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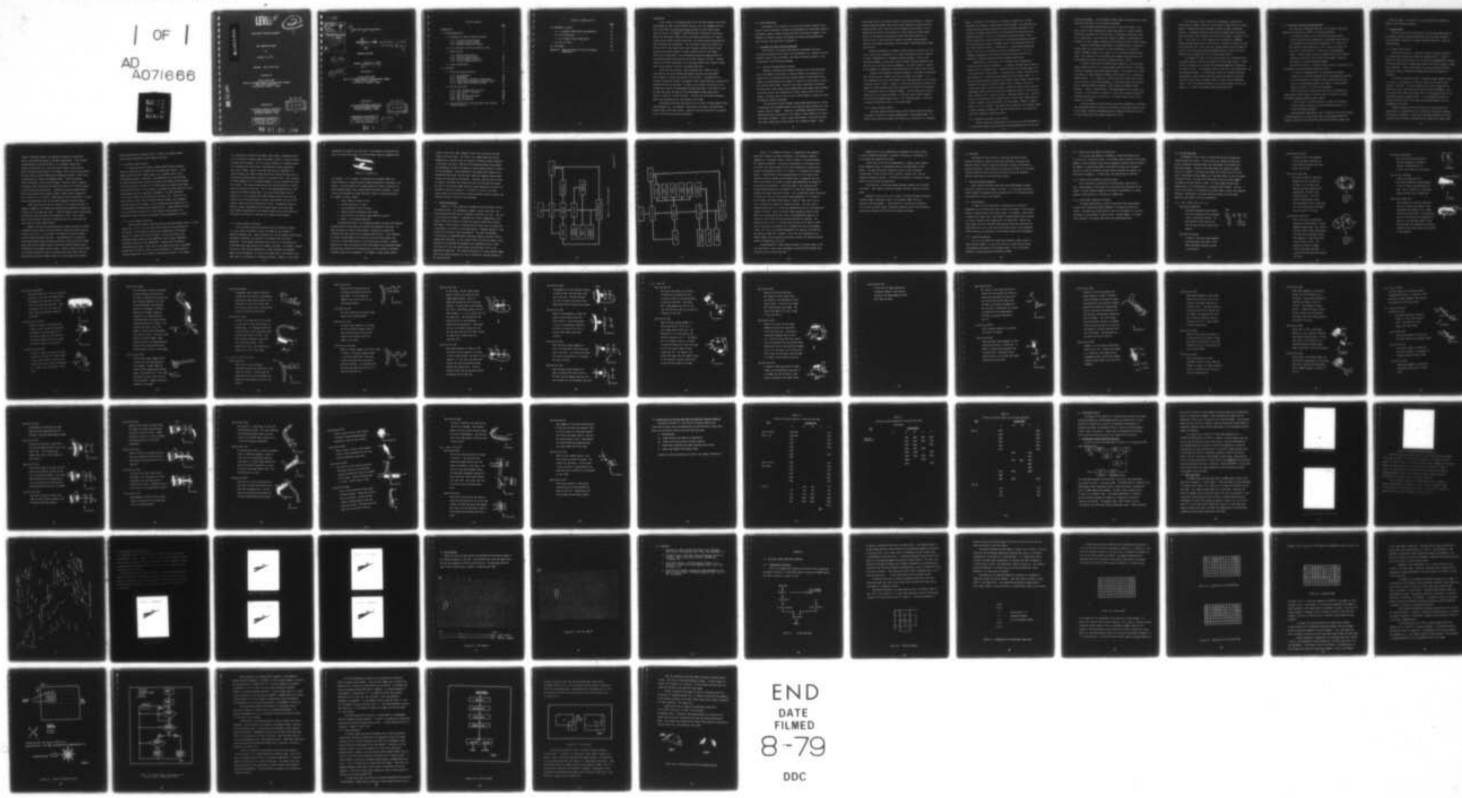

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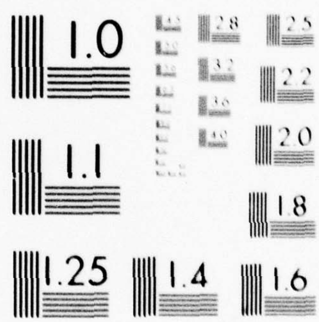

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INTELLIGENT TRACKING TECHNIQUES

FIRST QUARTERLY REPORT

for

December 31, 1978

CONTRACT: DAAK 70-78-C-0167

Presented to

UNITED STATES ARMY
Mobility Equipment Research and Development Command
Night Vision Laboratory
Fort Belvoir, Virginia 22062

Submitted by

Westinghouse Electric Corporation
Systems Development Division
Baltimore, Maryland 21203

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INTRODUCTION

Under contract to the Army's Night Vision and Electro-Optics Laboratory, Westinghouse has been investigating the design, test, and implementation of a set of algorithms to perform intelligent tracking and intelligent target homing on FLIR and TV imagery. has been investigated Research has been initiated for the development of an intelligent target tracking and homing system which will combine target cueing, target signature prediction, and target tracking techniques for near zero break lock performance. The intelligent tracker will monitor the entire field of view, detect and classify targets, perform multiple target tracking, and predict changes in target signature prior to the target's entry into an obscuration. The intelligent tracking and homing system will also perform target prioritization and critical aimpoint selection. Through the use of VLSI/VHSI techniques, the intelligent tracker (with inherent target cuer) can be applied to the fully autonomous munition.

During the first quarter, several meetings and a number of phone conversations took place between Westinghouse personnel and John Dehne, Peter Raimondi, and Capt. Ben Reischer of NV and EOL. A program plan was reviewed, preliminary analytic and computer results were presented, and additional program direction was provided. Included in this report are portions of the program plan, results of programming the DARPA algorithms, a description of the NV & EOL data base, and results of the Westinghouse freeze frame device applied to both 525- and 875-line data. The basis for the Tracker Assessment Section was provided by Capt. Ben Reischer of NV & EOL.

Westinghouse personnel participating in this effort include Thomas Willett, Program Manager; Dr. John Romanski, John Shipley, Leo Kossa, Tony Cangiliosa, Robert Bidney, and Richard Kroupa. Program review and consultation is provided by Drs. Glenn Tisdale and Azriel Rosenfeld.

1.0 SYSTEM DESCRIPTION

The purpose of this section is to assess the tracking problem in the light of current techniques, describe the requirements for intelligent tracking and homing, examine a system configuration which functionally responds to the problem, and allude to some of the appropriate image processing techniques which are more fully described in Appendix A.

1.1 Assessment of Target Tracking Techniques

This section is an excerpt from some work performed by NV & EOL.[1] The tracking techniques are divided into the categories of: presently fielded trackers, state of the art trackers, and future intelligent trackers. Each is described in the following paragraphs.

1.1.1 Presently Fielded Military Trackers

Presently fielded military trackers typically are of the single mode type, most commonly correlation or contrast (centroid of brightness) only. Target lock-on is achieved solely by operator command and the object being tracked is described merely as a group of illuminated pixels within a fixed or user defined track window. Failure of the tracker algorithms to delineate the boundaries of the tracked object coupled with poor window sizing (operator controlled) permits the introduction of clutter objects within the track window. Continuous loss of track in high clutter regions is typical for these non-adaptive tracking techniques.

The correlation tracker attempts window image registration on a frame-to-frame basis with repeated update of the reference image through use of the previous frame of imagery. Though this methodology compensates for moving objects within the track window it also permits clutter objects to influence the tracker confidence. Hence a target going behind a large bush may leave the tracker locked onto the bush and not the re-emerging target. Target obscurations affect the contrast tracker in much the same fashion. A moving target approaching another object causes both signatures to enter the track window and hence forces the centroid of brightness to be driven to a point between the two objects causing the loss of the originally tracked target. Failure of the operator to accurately control the track window size (a process known as "gate discipline") greatly exacerbates these breaklock conditions and burdens the operator with continually performing manual target reacquisition.

Another shortcoming of presently fielded trackers is caused by the use of less than optimal algorithms (e.g., binary correlation) which is required to permit implementation in reasonable realtime packages. Even so, the fabricated hardware is often bulky, special purpose (mission dependent) hardware and has a significant power consumption. This often requires a redesign of the hardware to compensate for the peculiarities of a new mission scenario.

Perhaps a more important limitation, however, is the implicit assumption that one and only one "target" exists to be tracked in the image. It is this assumption which lies at the heart of the "gate discipline" or correlation "reference update" problem. Further, it limits the technology to tracking one target at a time although the military necessity of high rate of fire depends on simultaneous tracking of multiple targets. Finally, because the target is known only by its intensity profile, the centroid (hence tracker aimpoint) will vary with changing target aspect. This "aimpoint wander" is often one of the most significant errors in a tracking system.

1.1.2 State-of-the-Art Trackers

The newly emerging state-of-the-art (SOA) target tracking techniques incorporate a variety of tracking methodologies in a multimode format. We begin to see interaction between the tracker and a controller in a "handshake" manner. An example of this might be a synergistic combination of several algorithms for achieving a highly stable tracking system. The algorithms may include contrast and edge tracking along with correlation tracking for the derivation of target motion and for pixel registered scene tracking during breaklock conditions. The use of LSI hardware techniques permits a more optimal selection of tracker algorithms for realtime applications and permits the incorporation of advanced multimode trackers in terminal munitions and man-in-the-loop RPV scenarios. Microprocessor - based tracking technology permits fine tuning of algorithms for specific applications. This is a tremendous improvement over fielded (hard-wired) trackers which are not adaptable to improved algorithms without hardware modification.

Unfortunately, SOA trackers still encounter severe problems when tracking in high clutter environments. For example, the SOA centroid contrast tracker now has an adaptive gate. Assume the target being tracked moves into an area with other intense objects. Perturbations in tracker confidence force the system into a reacquisition mode within this high clutter region. As the tracking gate widens to reacquire the target, clutter objects significantly influence the tracker algorithms and may drive the system to lock onto a clutter item rather than the true target. Additional factors which cause the algorithms problems include low target-to-background contrast, sun-to-horizon angle (shadows, glint), target-sun aspect, background texture, etc. These SOA trackers still operate only on single targets but have some limited aimpoint analysis capability due to delineation of target edges. However, "aimpoint wander" is still a problem. Even though they provide the best tracking schemes to date, multimode trackers still lack the sophistication for application into fully autonomous terminal munitions.

1.1.3 Advanced Intelligent Target Trackers

Research has been initiated under this contract for the development of an intelligent target cueing and target tracking methodologies for near zero breaklock performance. The intelligent tracker sought should possess the unique capabilities described in the following paragraphs.

The intelligent tracker should be able to track many targets in the sensor field of view simultaneously without duplication of tracker hardware. Tracker/cuer synergism will allow the cuer to continually inform the tracker of all cued objects. The tracker will update its memory to acknowledge the existence of a new target or reconfirm the location and track of known targets.

Since the intelligent tracker works in conjunction with a target cuer, identification (or classification) of the tracked object is possible as feature information (range, size, shape, etc.) is extracted from the sensed scene. This capability (classification) also permits prioritization of the tracked multiple targets and critical aimpoint analysis of each.

Following closely with the Identification capability, the intelligent tracker should prioritize all tracked targets within the field of view based on apriori knowledge about target type and threat. This analysis will permit the operator to always engage the highest threat target first in a multiple target scenario. It is important to realize that such target prioritization is by no means a cut and dried procedure. Prioritization must be considered hand in hand with threat assessment. Which should be assigned a higher priority - a tank or a SA-9 missile? The answer depends on the scenario and situation. If the tracker is located in a tank, then an enemy tank would be of higher priority than a SA-9 missile. The reverse might be true if the tracker is in an AAH.

Since the target has been classified and track information is available, the intelligent tracker can point to the location of the most vulnerable point of the target. Munitions deployment would be directed to that point since a hit there would yield the highest probability of kill.

The intelligent tracker should track autonomously, automatically reacquiring the target as need be, from the time of acquisition until time of impact or completed munitions deployment without any human intervention required. An extremely important and difficult problem occurs for targets entering, leaving, and re-entering the field of view (FOV) as happens in the RPV. In such cases, it is very important for the tracker to "remember" targets outside the FOV, their classification, direction of travel, and time since leaving the FOV. Thus, after the current highest priority target has been hit, the tracker would know approximately where to look for the next highest priority target even if it was now outside the FOV.

The problems of track loss and reacquisition, one of the weak points of present trackers, should be overcome by the intelligent tracker. Current tracker technologies only consider the background immediately surrounding the target in track. This approach leads to track loss as the target moves into new background regions. The intelligent tracker will contain algorithms which monitor a broad context around the target and predict the expected variation of the target's signature before it enters the new background region. Thus, this advanced approach will allow the tracker to follow the target as it crosses the boundary between background types.

1.2 Intelligent Tracking and Homing Problem

The reasons for considering some sort of intelligent tracking and homing were stated by NV & EOL[2] in the following paragraph.

"...Present day target trackers and terminal guidance homing systems encounter severe degradations in performance when operated in environments with high clutter backgrounds. The reasons for the failure of these techniques is their inability to alter the description of the target as it passes into a new background region. Instead, these trackers and homers wait until the target's correlation coefficients diminish and then attempt to reacquire the target in a totally undesirable domain".

NV & EOL[2] then went on to state the direct technical problem which the Intelligent Tracking and Homing system must attack.

"...A system of algorithms which can quantitatively identify a target and its present background but can acknowledge the approach of a new background in the target's path, characterize this new region, and intelligently predict the target's signature BEFORE (capitals are NVL's) it enters the new domain".

There are additional features which this set of algorithms must possess which further remove it from the realm of present day tracking and terminal guidance homing systems, namely[2]

"...must be able to perform such task as target prioritization, critical aimpoint selection, and multiple target tracking...on visible and infrared imagery".

These additional requirements force a significant distinction between trackers operating in a small window around a pre-assigned target and trackers responsible for prioritizing and tracking multiple targets over the entire image. To prioritize, e.g. the system must be capable of detection and recognizing targets.

1.3 System Concept

The basic parts of the system concept for the Intelligent Tracking and Homing System are target prioritization, multiple target tracking, critical aimpoint selection, and target signature prediction. These are described below.

1.3.1 Target Prioritization

Target prioritization is necessary in order to identify as quickly as possible that target which presents the greatest threat. A second reason for target prioritization is to nullify such countermeasures techniques as driving a high priority target among several low priority targets to merge their signatures. Target prioritization also eases the need for precise pre-launch targeting information obtained under difficult battlefield conditions.

In order to establish an order of importance among potential targets in a scene, it is necessary to be able to detect and classify all the targets in the scene. This must be done over the entire frame and not limited to a small window because of imprecise launch information. This must be done with sufficient accuracy and in a short enough time to allow an effective change to another target. It is not enough to be able to classify targets at such a short range that platform dynamics will not accommodate a new course.

Present trackers do not have the ability to perform their own acquisition as is required here, nor do they have the ability to handle a full frame of information. Target cuers can perform detection and classification based on features extracted from the image such as edges, edge lengths, thresholded shapes, the congruence of edges and thresholded shapes, and orientation angles of the edges among others. These features are manipulated to form new entities, e.g. perimeter length, area, length to width ratios, etc. which are used to reach a classification decision concerning some object in the image. These classification entities are part of the resident program and are designed to handle a wide variety of target aspects, ranges, and approach angles. Under the expected clutter conditions in which the intelligent tracking system is expected to operate, these features must be modified on-the-fly for effective target classification and prioritization. Consider the previous example where a high priority target drives among a group of lower priority targets and only a portion of it is visible. Modification of the classification criteria will be discussed more fully in the Target Signature Prediction Section.

Target cuers have the ability to handle a full frame, 525-lines, of imagery at speeds of 3-10 frames per second and the capability to detect and classify up to 30 targets per frame. These 30 targets, their classification, and position within the frame are maintained in a file. Then a simple form of prioritization consists of reordering the file, after every cued frame, based on target classification.

However, the cuers do not provide data at speeds necessary to handle a platform control system, only the presently fielded and state-of-the-art trackers can do this. So the tracker is directed to follow the highest priority target provided by the cuer. The combination of a target cuer and frame-to-frame tracker provides the ability to survey the entire frame, detect and classify targets therein, and provide frame-to-frame tracking information on the highest priority target. Should a higher priority target be discovered, during the course of tracking some other target, the cuer would direct the frame-to-frame tracker to the new target and continuous tracking data would be obtained from it. Further, the frame-to-frame tracker would be provided a target image by the cuer.

1.3.2 Multiple Target Tracking

To track more than one target, frame-to-frame trackers generally require a duplicate set of hardware for each additional target. In autonomous munitions or RPV's where volume is at a premium, this is not a satisfactory approach. Alternately, the combination of a cuer and frame-to-frame tracker provides continous tracking on the highest priority target and tracking data at the rate of 3-10 track points per second on the others over the entire image. In this fashion, 30 targets per second could be tracked simultaneously with the same piece of hardware. The latest positions of the other targets are available from the target list. From this list, target tracks of other than the highest priority target, can be computed even when they leave the image. Visual contact with these targets can be re-established by following these computed tracks. These additional tracks are of sufficient accuracy to allow the frame-to-frame tracker to be directed to anyone of them and continuous tracking immediately initiated.

1.3.3 Critical Aimpoint Selection

Frame-to-frame trackers have the ability to perform aimpoint based on a known target type. That is, the cuer again must provide the classification for the tracker. This algorithm is particularly appropriate at long range because it is based on the exterior shape. As the range closes, this algorithm becomes suspect and the additional interior shape information provided to the cuer is more appropriate. Assuming that the features extracted are the same as those used at long range by the cuer, the problem becomes one of trying to classify interior portions of a target based on the same features set, but different classification entities. For example, it is desirable to be able to use edges, edge lengths, thresholded shapes etc. to be able to classify treads and turrets of tanks in order to provide accurate close-in homing. This is a classic problem in all homing systems, e.g. torpedoes which do not have a high resolution sensor appropriate for close-in homing. Again, since high data rates are imperative for close-in homing, the frame-to-frame tracker must provide the data input to the munition platform control system on a continuous basis. Here, assuming the turret happens to be a desirable aimpoint, the cuer isolates the turret as an entity. The frame-to-frame tracker can then be directed to initiate centroid tracking on the turret. This is the same procedure used at long range on the external target shape. The cuer and the tracker work together for, in the case where the target becomes partially obscured, the centroid can be calculated based on target classification and the visible portion, rather than the visible portion, alone. The aimpoint selection based on interior shape detail also provide a check on the long range classification algorithms, for the interior detail must be consistent with long range classification in the case of a correct classification.

1.3.4 Target Signature Prediction

The intelligent tracking and homing system is required to operate in a high clutter environment in which the target may be occluded in a number of different ways. These occlusions will not only hinder classification and aimpoint porcesses, but they will act to break track and inhibit detections. At the feature extraction level, not all of the features will be available once some portion of the target is occluded. For example, consider the case of a dark target travelling on a light road where the shoulders appear as dark background. As long as the target stays in the middle of the road, there is no difficulty in tracking the target. However, as the target approaches the shoulder, the front part of the target will merge with the side of the road (See Figure 1-1) and the target cannot be segmented from

Figure 1-1. Obscuration

the shoulder. If, for example, we demanded four perimeter edges for a target detection, no detection would be made because one of the edges is not present. If we had modified the target detection criteria, on-the-fly, to three perimeter edges, then a target detection would be achieved. To have successfully modified the target detection criteria, we would have had to do a number of things, namely;

1. detect target in middle of road
2. estimate direction of travel
3. note background in path of target
4. compare potential background with target
5. note conflicts with present target detection criteria
6. modify to allow target detection

To perform these steps in the example described, we might have compared the gray levels of the target with those of the shoulder of the road. If some difference was found we might change a threshold to preserve the difference and stay with the four perimeter edge criteria. If no difference was found, we might modify the criterion and use only three edges, this calls for a similar modification in the classification criteria. Another possibility is that the presence of the target against the background changes the gray scale pattern over the merged area, and this pattern is different from other parts of the background. For example, a light target passing behind a dense dark clump, changes the gray scale value over the dark clump at the pixel level. The latter is an example where the initial merging acts to confirm, deny, or establish a different target signature. In any event, the cuer is looking at the background ahead of the target and attempting to predict the change in target signature before it enters the new background. Having determined a new target shape because of an approaching obstruction, the cuer must inform the frame-to-frame tracker and pass the new shape to the tracker. Similarly, when the cuer is ready to analyze a new frame, the tracker must tell the cuer where the target was seen on the previous frame and pass on some characteristics which are relevant to the cuer's analysis. In Sections 2.1 and 2.3, we shall discuss some of the more difficult tracking scenarios found in the NV & EOL data base and their location in the data base.

1.4 System Configuration

Figure 1-2 is the system block diagram for the Intelligent Tracking and Homing system. The preprocessor, segment, feature extraction, and classification functions may be considered as portions of a cuer. The cuer is the controlling element. It provides for initial segmentation of the image, directs the tracker to follow that detected target which exhibits the highest initial priority, based upon mission data (such as probability of occurrence in relation to scene description). Segmented objects of lower priority are stored for later consideration. The cuer then performs classification of segmented objects based upon features extracted from the preprocessed image data. As the tracker follows the priority target, these features will be modified and updated by the signature predictor, which will make use of the high speed tracker position data as well as the preprocessed image data. The signature predictor will supply modified image data to the feature extractor for use in obtaining an improved feature set for classification.

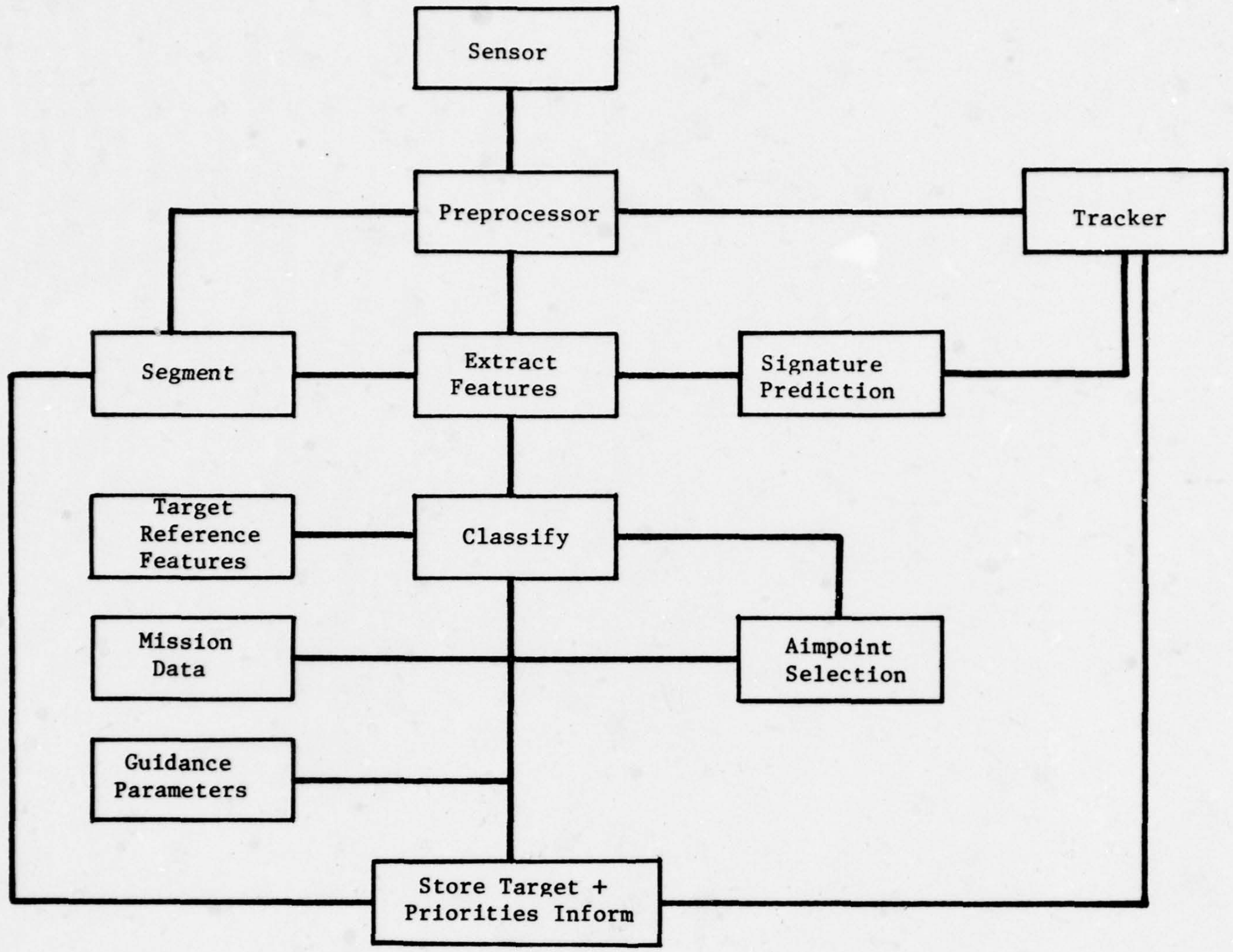

Figure 1-2. System Block Diagram

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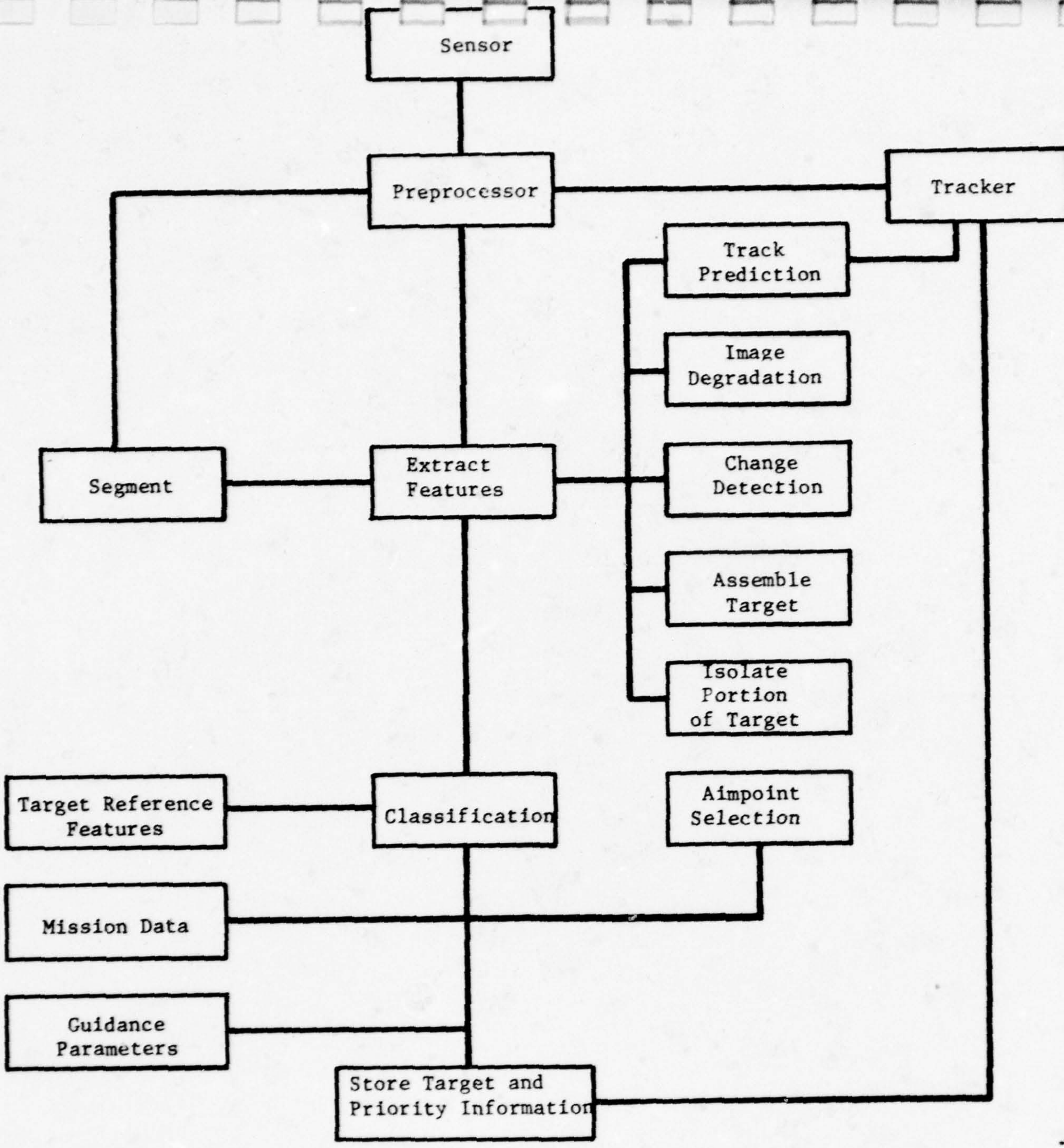


Figure 1-3. Detailed System Block Diagram

79-0503-V-2

Figure 1-2 is repeated as Figure 1-3, additionally the signature prediction fucntions are shown individually. This breakout should be regarded as a "straw-man" system in that it serves as a starting concept for signature prediction. Successive registrations by the tracker serve as a basis for a least squares fit for track prediction; a second order, recursive implementation using 5 or 6 points is a reasonable first approximation. Then portions of the background which lie in the path of the target are placed in memory and the target image is superposed and cued. From this we obtain an estimate of target image degradation and adapt the cuer functions accordingly. To add more power to the system, we shall perform change detection on the target as it enters the background and assemble the target from these features. This accomplishes several objectives; it serves as a check on the predicted image degradation, it is useful in the case where the target moves behind a screen of trees, and it can be used to assemble the target for aimpoint selection. The final step in signature prediction is to isolate the appropriate portion of the target for aimpoint selection. Hence, we predict image degradation ahead of time, modify the expected feature set, check on the prediction, modify it if necessary, and isolate the target portion required for aimpoint. The purpose of the tracker is to provide position data at the field or frame rate of the sensor, and thereby incur a minimum time lag to the guidance system. The cuer, as presently implemented, will operate at one-third to one-tenth the frame rate. However, if the cuer can be operated at the higher speeds, and with adequate positional accuracy, the tracking function could be accomplished by the cuer.

The preprocessor is shown separate because it provides inputs to the cuer and tracker. Appropriate enhancement and prefiltering functions are carried out of the sensor data rate.

Segmentation can be accomplished by thresholding and level slicing, as with the Maryland algorithms, by gradient following, as with AUTO-Q, or by an appropriate combination of these.

Features may consist of such measurements as lengths, areas, memements on the segmented areas, or measurements made on extracted edges as with AUTO-Q. The edges which offer end-point position as well as polarity (relationship of light and dark sides), provide a natural entry into the problem of aimpoint selection. If sufficient resolution is available, target details can be outlined and identified.

Classification is based upon stored reference features for the target of interest. When adequate resolution becomes available, aimpoint selection begins.

Appropriate mission data can be stored, including information regarding expected targets, background context, and expected target sizes as a function of mission dynamics. Prioritization is carried out on the basis of all stored available target information, beginning with initial detection, and moving up through classification and aimpoint selection.

2.0 DATA BASE

The purpose of this section is to describe the more difficult tracking scenarios as found on the NV & EOL Data Base, to describe the Data Base itself, and to classify the Data Base in terms of the difficult tracking scenarios. These difficult scenarios were alluded to in the Target Signature Prediction Section and will be used to design the Signature Predictor Algorithms for the Intelligent Tracker.

2.1 Difficult Tracking Scenarios

These scenarios describe cases where the target becomes occluded such that a portion of the target is not seen. In a few cases the target almost completely disappears and then appears again at a different position not predicted by the last seen heading.

2.1.1 New Background

In these cases the background is characterized as relatively homogeneous but of similar gray scale to that of the target. Also the background is something other than another target. For example, a dark target is moving onto a dark road, a dark target is moving along the dark shoulder of a road, or moving along a muddy path in an open field. Another case occurs when a APC turns and moves away from the sensor thus obscuring the light front and its gray level now closely matches that of the background. Similar remarks can be applied to light targets against light backgrounds.

2.1.2 Target Shape Merging

This is a case where the target moves behind or among a group of lower priority targets. In this case, part of the high priority target is occluded by the presence of the other targets. This is particular difficult at long range and low platform altitudes.

2.1.3 Target Partly Occluded by an Obstruction

In this case, the target is occluded by a natural obstruction such as a tree, hill, or bend in a road. In all these cases, a portion of the target remains in view, and before that portion disappears, another portion re-appears. An example is a tank moving behind a tree where the front part disappears, the rear is visible, and before the rear portion completely disappears, the front portion reappears. In these cases, the obstructions are vertical.

2.1.4 Target Partly Occluded by Terrain Features

Here, the target is obscured by low lying shrubs, bushes and the like. Other examples include small hills which hide the lower parts of the target. The most frequent example of this type of obscuration is a target moving in scurb terrain or a clearing in a wooded area.

2.1.5 Target Almost Completely Occluded

The target moves behind a screen of trees where the target appears as one or more bright spots moving randomly in the general direction of travel. The target may be moving down a road, but the geometry is such that the target is seen through a screen of trees. Another example is a target moving through a thick woods where there are scattered openings.

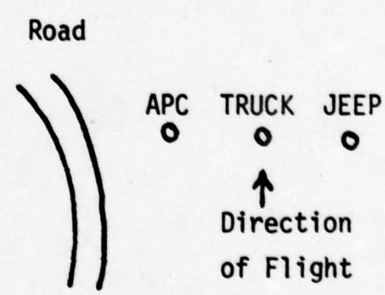
2.2 NV & EOL Data Base

The purpose of this section is to describe the NVL FLIR data base supplied under this contract. For the first pass through the data base, we were interested in moving targets with some amount of obscuration and long range targets. Portions of the tapes where the targets are larger will be of interest in the future work under this contract but not at this point. Description of tape segments will have more detail if they fall within the above criteria. We expect this descriptive log on the other segments to expand as the work focuses on them. The index number for each tape segment refers to the length meter on the Westel tape recorder. This may vary for the reader's case depending on how much tape is used in the threading operation. Nevertheless, the index should be within ± 25 of the meter reading on the reader's 875-line tape machine.

2.2.1 Tape "11/10/77 Runs 1,2,3, etc.

Tape Position 0000-0370

Helicopter approaches three targets which are stationary and not obscured; a man is standing on the APC. The APC presents a front aspect, and both the jeep and truck present side aspects.



Tape Position 370-670

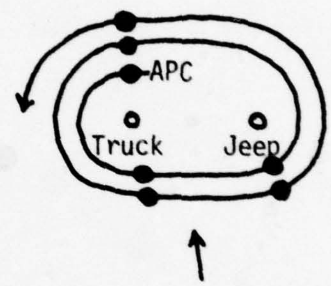
A repeat of the above target geometry with the targets seen from a longer range and higher altitude; the man is not present.

Tape Position 710-1220

A repeat of the 370 run geometry with a side aspect presented by both the APC and truck and a front aspect for the jeep.

Tape Position 1265-1580

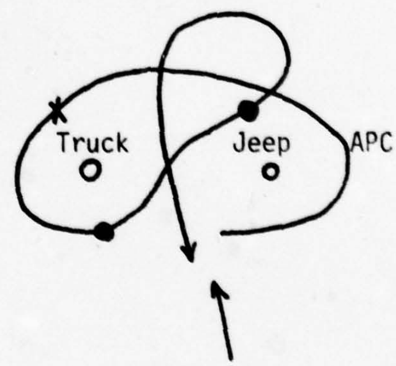
APC circles other two stationary targets which are not obscured. The dots (•) on the APC track indicate positions where the APC shape merges with that of the stationary target. The first several "target merges" occur when the targets are 4-8 lines high; the latter merges occur for target sizes in excess of 15 lines.



Helicopter Direction of Flight

Tape Position 1780-1950

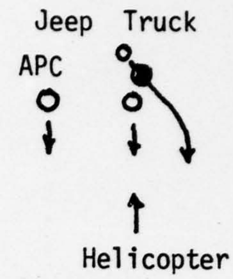
APC circles other two stationary targets and then performs a circular maneuver between them. Dots indicate positions where the APC shape merges with that of the stationary target. APC signature is faint along right side of initial circle. This sequence was taken at longer initial range than 1265-1580. "X" indicates position where APC exceeds 4-8 lines.



Helicopter Direction of Flight

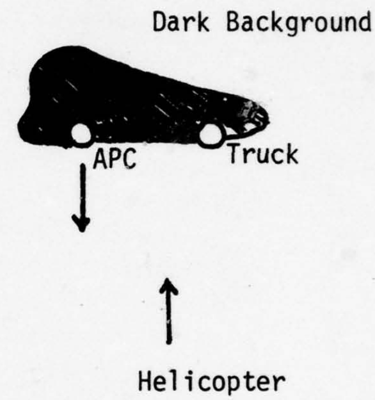
Tape Position 2032-2400

Truck initially positioned behind jeep and signatures are merged at location indicated by dot (•). Initial size in the 4-8 line category.



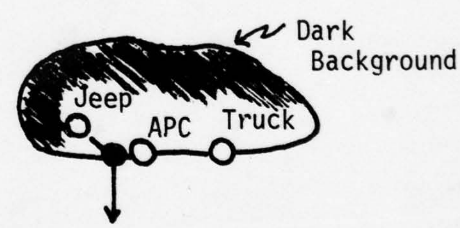
Tape Position 2500-2800

Targets are stationary until helicopter approaches to approximately 8 lines of target, then APC moves forward. APC is initially in a dark background and moves into a lighter one.



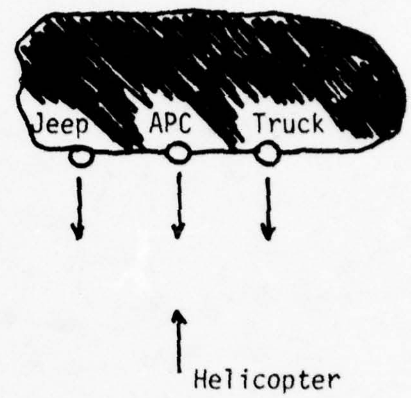
Tape Position 2850-3180

Three targets are initially stationary, with two of them on the edge of a dark background which appears to be a muddy portion of an open field. The jeep moves next to the APC causing the signatures to merge (•), and then moves ahead a short distance where the signatures are distinct. Targets are very small during first portion of the sequence.



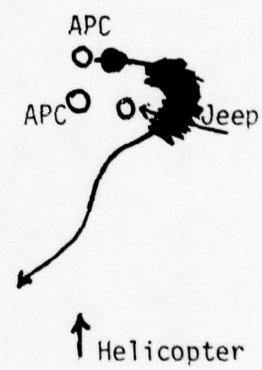
Tape Position 3200-3660

The three targets are initially stationary and small; there are a few frames where the operator switches from the wide field of view to the narrow one. When the targets are still less than 8-10 lines, they move together toward the helicopter.



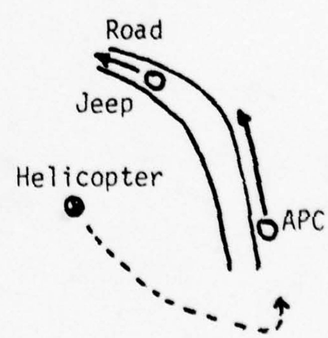
Tape Position 3700-4000

Targets initially at long range and closely spaced; the two APC signatures are merged at position marked by (•). APC moves through dark and light background and sequence ends with a close up of front quarter of moving APC.



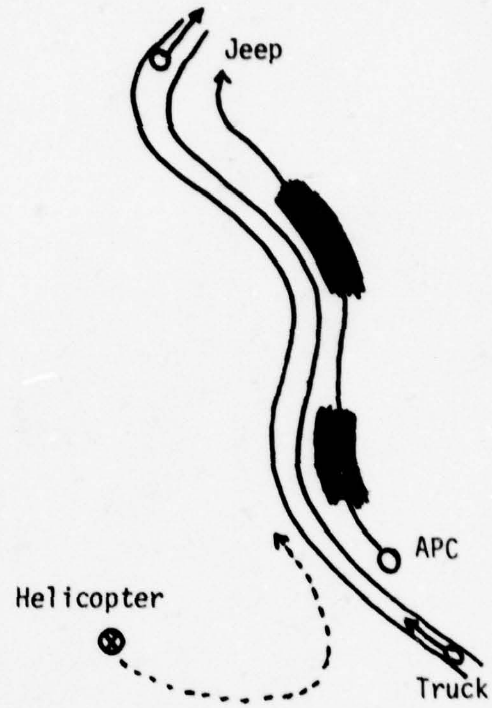
Tape Position 4100-4300

Initially a jeep is seen from the side and then rear aspect as it moves along a road. Then an APC is seen at close range from the rear aspect and followed as it moves along the shoulder of the road.



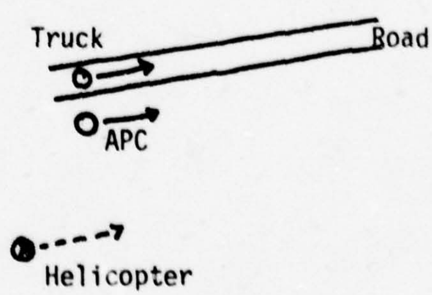
Tape Position 4300

First the jeep is seen at long range by the helicopter at position (X). The jeep is moving on the road and the jeep signature appears to be faint and moving through light and dark patches of background. The APC is then seen as it moves along the shoulder of the road and the APC signature merges into light and dark background patches as it moves. The sequence ends with narrow field images of the APC seen from quarter rear and rear aspect. The truck, seen briefly in several frames, comes around the bend in the road where the jeep was first seen and both truck and APC appear close-up, in the image.



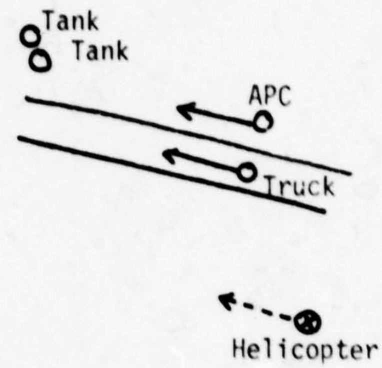
Tape Position 4760

Side and rear aspect images of APC and truck as seen from medium and close ranges. Several times the target outlines merged and then drew apart. Both targets are in the image continuously until a final close-up shot of the APC. Targets seem to be running at high speed.



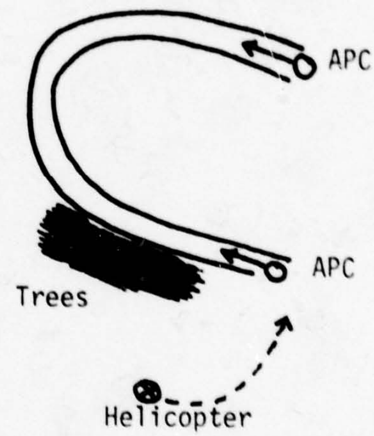
Tape Position 5000

An apparent mirror image of 4760 with the APC and truck moving in the opposite direction and the closest target to the helicopter is the truck; sensor comes upon two stationary tanks at 5270 during course of tracking truck and APC.



Tape Position 5365

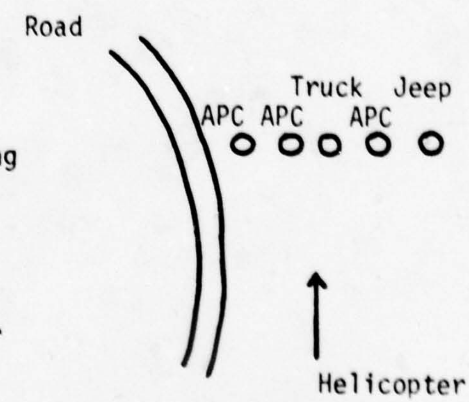
The APC in the lower part of the figure is seen from the side, moving fast, at medium range. It disappears behind the screen of trees, and is seen again when the helicopter gains altitude. Then the helicopter switches to the other APC, moving more slowly. Side, quarter-rear, rear, and quarter-front aspects are seen at close ranges.



2.2.2 Tape "11/11/77 1030 hours"

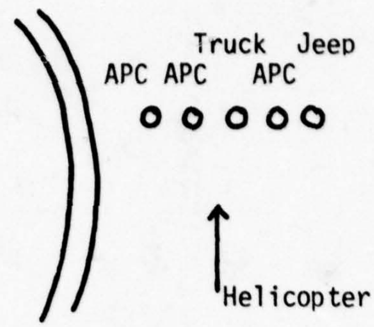
Tape Position 380

There are five closely-spaced, stationary targets seen beginning at long range and closing. At long range the right-most APC and truck signatures are merged and there appears to be only four targets.



Tape Position 800

There are five targets which are stationary and pointed toward the helicopter. At long range the images of the truck and APC to its right appear merged.



Tape Position 1000

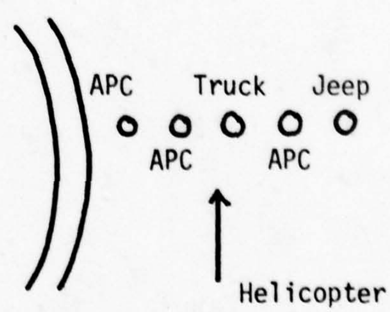
The same as 800 with helicopter range, aspect, and altitude changes.

Tape Position 1320

The same target geometry as the above and the helicopter approach angle is such that the merged truck and APC images do not separate until the range is very short.

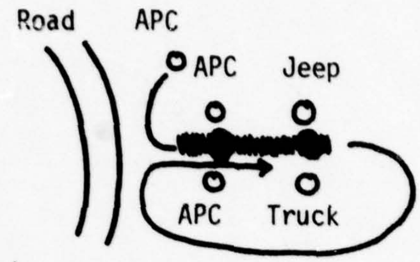
Tape Position 1730-2300

Repeat of target geometry but initial range is longer. Helicopter approach angle is such that hidden APC is seen more clearly but merges with the truck as approach continues. The left-most APC has the hatch down and the APC to its right has the hatch up.



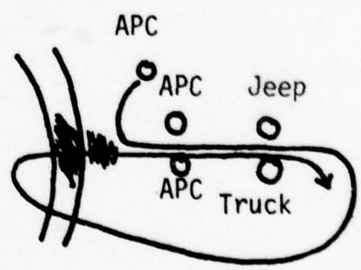
Tape Position 2430

At long range, the APC images appear merged, similarly the jeep and truck images appear merged. There is a muddy path between the four stationary vehicles. The moving APC, which appears dark with a light front, merges with the other targets, as it passes among them, and the muddy path. The dots (●) show the merge positions of the stationary target with the moving APC. Front edges are lost, and target bottoms are lost. The jeep and truck are very light targets; the moving APC is darker than the stationary APC's.



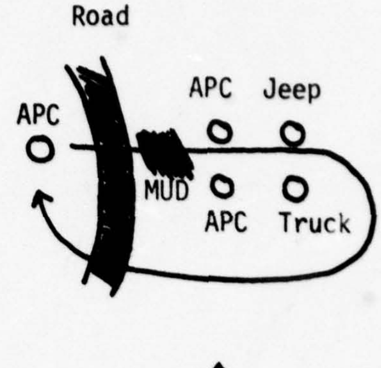
Tape Position 3100

Same target geometry as 2430, but the helicopter altitude appears to be lower so the occluding targets are seen as closer together. In this case, the moving APC crosses the road twice before passing through the targets again. The dark patches on the road and shoulder provide obscuration for the dark APC.



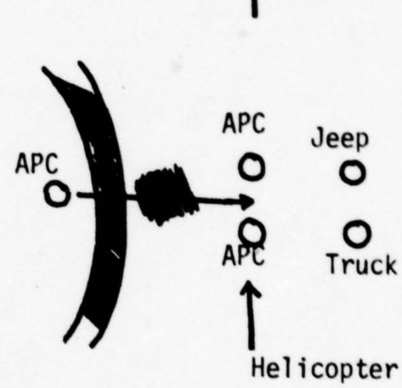
Tape Position 3700

Same geometry for the stationary targets as 3600 but this time APC starts from across the road. The dark APC must pass over the dark road and over the muddy ground before reaching the targets.



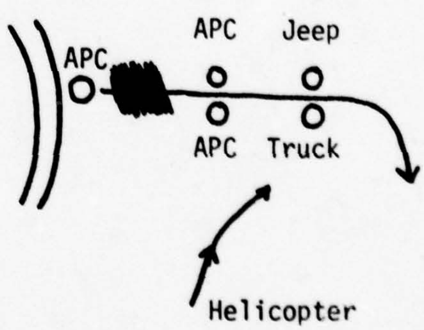
Tape Position 4380

Repeat of same geometry as 3700, but range is much shorter before APC begins moving. Closing helicopter is seen as representing a munition, and APC just reaches first set of vehicles when impact would have occurred.



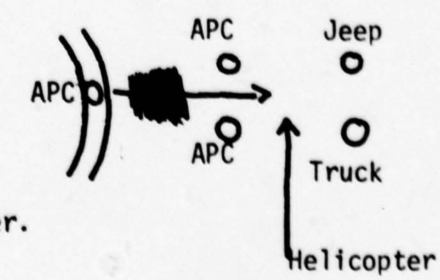
Tape Position 4855

Same stationary target geometry as above, but moving APC starts from right side of the road. The closing helicopter flies over the moving APC as it emerges the truck and jeep.



Tape Position 5330

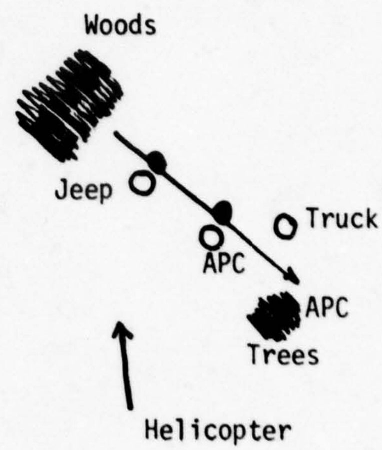
Same stationary target geometry as above, and moving APC starts from on the road; the APC emerges from the first set of targets as the helicopter flies over.



2.2.3 Tape "#4"

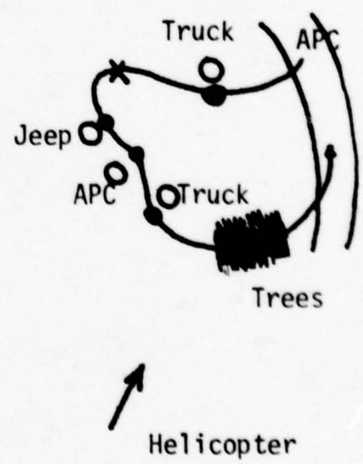
Tape Position 240

APC moving from woods into clearing. The woods at the beginning of the run and the trees at the end partially occlud the moving APC. The moving APC's image merges with that of the jeep and stationary APC at the positions indicated by dots (●).



Tape Position 500

Same stationary target geometry as 240 but moving APC starts out as dark target against dark road. The moving APC is 4-8 lines high at the position denoted by an "X". The moving APC is occluded by trees as it passes the truck and moves back toward the road. Initial helicopter ranges are much longer than 240. The image of the moving APC merges with the images of each of the stationary targets successively at the positions shown by the dots.

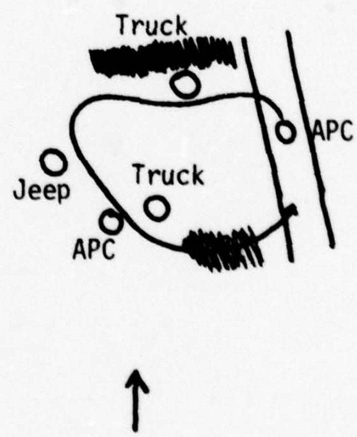


Tape Position 803

Repeat of 500 except APC moves more rapidly so that target sizes are smaller at run completion as helicopter closes. Also end of run shows APC traversing the road longer. APC starts from edge of the road instead of the road itself.

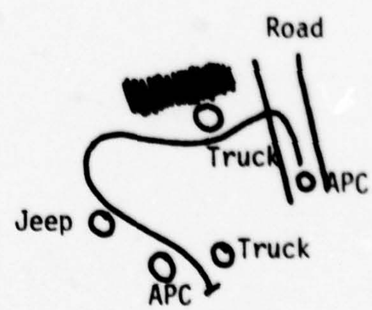
Tape Position 1080

Repeat of previous run and target geometries except that moving APC starts from the road. Long range is maintained throughout most of this run. Occlusions seen with trees shielding the moving APC from view and APC shape merging with that of the stationary targets. Also, as in the other runs in this series, 500 and 803, the APC moves along the edge of a woods in the top part of the run.



Tape Position 1380

A repeat of 1080 except done at longer range, and the moving APC stops when it is between the APC and truck so that there is merging of the target shapes.

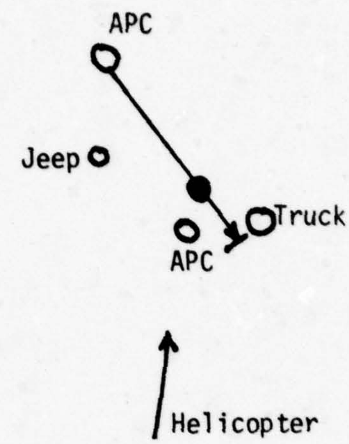


Tape Position 1610

A short set of frames showing the stationary targets in the clearing arrayed in the same geometry as 580, 803, 1080, and 1380.

Tape Position 1870

Run starts at long range and high altitude such that targets are very small. Targets are stationary for about half the run and then the APC moves from the edge of the woods to between the APC and truck. Obscurations are caused by ground cover and shape merging with APC at position indicated by dot (•).

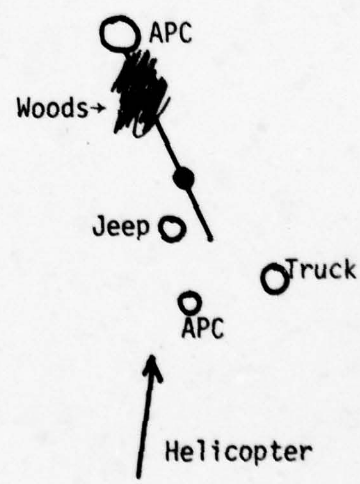


Tape Position 2200

Sensor operator seemed to be scanning for entire run length.

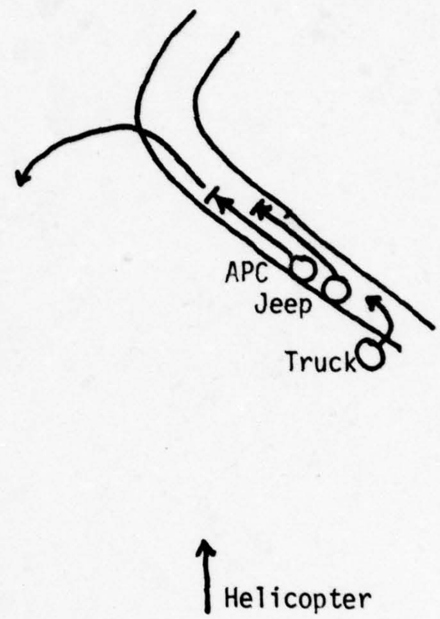
Tape Position 2800

Same stationary target geometry as 1870. Moving APC position is further back in woods, so obscurations sometimes mask the entire APC. Helicopter closes rapidly and at such an angle that shape merging occurs with jeep.



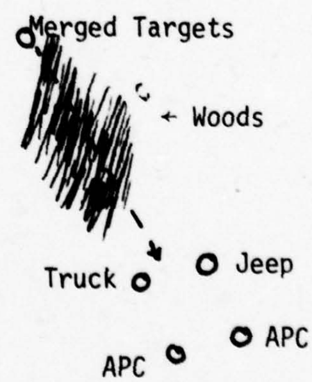
Tape Position 3090

Targets are initially grouped, with shapes merging, as shown. APC moves a short distance up the road and stops; jeep then moves up to position slightly behind APC so that their shapes merge. Then as truck moves to merge with the APC and jeep, the APC moves forward and then into woods. The truck follows, passing the jeep, the APC in the woods. Trees and brush occlude all or parts of the targets as the move along the road and in the woods. The jeep moves up the road at the end of the run.



Tape Position 3700

Movement of four target through woods shown in this run. Targets first appear as a single dot, then appearing and disappearing dots, and the four targets emerge from the woods at the end of the sequence.



Tape Position 4400

Same target geometry as 3700 except targets are initially closer to the clearing, helicopter range and altitude are less. This means that the initial portions of the targets seen are larger, and complete occulsions are of short duration and near the beginning of the run. Many examples of partial obscuration.

Tape Position 4850

Repeat of 4400 except helicopter is closing faster and altitude is higher. Helicopter closing angle is such that complete occulsions are obtained with fairly large targets.

Tape Position 5300

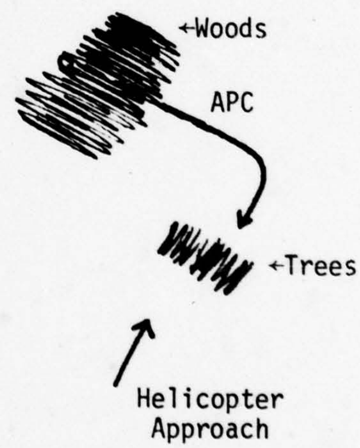
Same target geometry as 4850. Helicopter starts at closer range and targets are always, at least, partially visible. Examples of partial obscuration and shape merging.

Tape Position 5650

Same target geometry as 5300 except target start from further back in the woods. This provides examples of complete obscuration as well as partial. Also examples of shape merging. Targets move out of woods, across clearing, and into woods on the other side of the clearing before helicopter flies over.

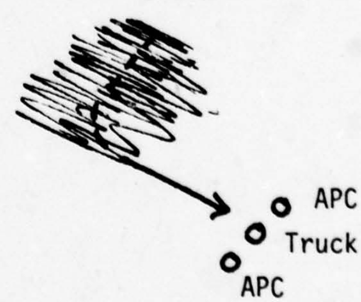
Tape Position 6000

Single APC, at fairly high speed, appears as a dot, partially obscured, then emerges from the woods. The APC then turns in the direction of incoming helicopter and moves among trees on the other side of the clearing.



Tape Position 6270

Three targets, with merged shapes, are seen moving through woods as alternating white dots, then partial obscuration, and as complete targets at the end of the run.



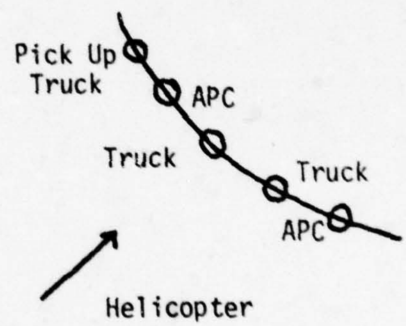
2.2.4 Tape "11/14/77"

This tape consists of stationary targets throughout which were in a clearing. Since there was no target movement, this tape was not analyzed for tracking purposes.

2.2.5 Tape "#5 11/15/77"

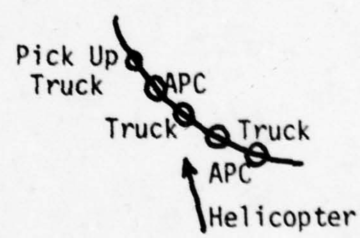
Tape Position 330

Helicopter approaches stationary targets in trees along border of woods. Tank appears as dark target with light turret.



Tape Position 600

Same target geometry as above, but helicopter modified the appraoch angles.



Tape Position 840

Same target geometry as above but helicopter approach is at greater altitude and approach angle of 600.

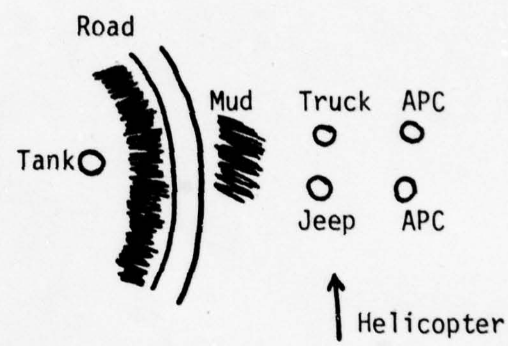
Tape Position 1100

Same target geometry as above with helicopter starting run at longer range.

Tape Position 1395

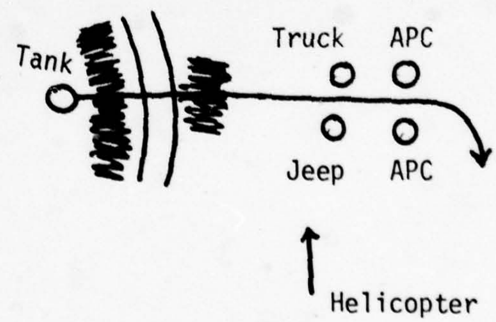
Same geometry as 600 with long range images and much shape merging as obscuration. Approach speed appears slower.

Tape Position 1750



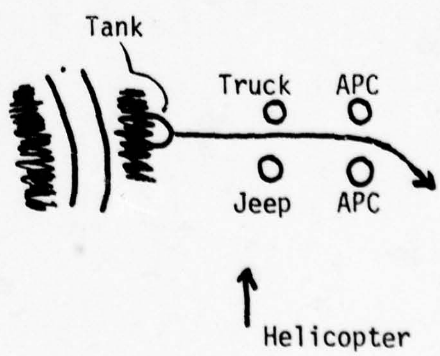
Targets are stationary in open field. The tank and muddy portions of the field appear dark. The truck and jeep appear light, and the APC's appear as gray targets.

Tape Position 2030



Same initial geometry as 2030, but tank moves across road and through the two pair of stationary targets. Tank undergoes obscuration with backgrounds on left and right sides of road and then shape merging with each pair of targets.

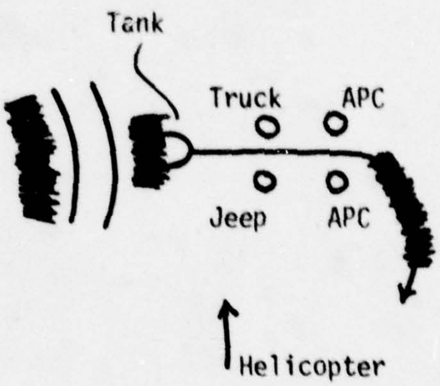
Tape Position 2300



Tank starts partially in mud to the right of road and passes between pairs of targets with shape merging.

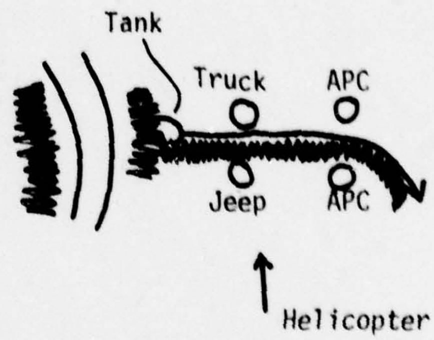
Tape Position 2560

Repeat of 2300 except at longer range and slower helicopter approach speed resulting in smaller targets. Muddy portion of field to the right of targets provides obscuration of tank with background.



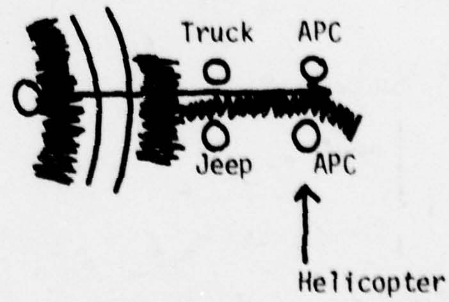
Tape Position 2910

Repeat of 2560 but now muddy path has been worn between the target pairs so that bottom of tank over entire run is obscured.



Tape Position 3180

Tank starts from left side of road; helicopter is at long range, initially. Helicopter flies over when tank is between the two APC's. Bottom of tank is only visible at the beginning of the run.

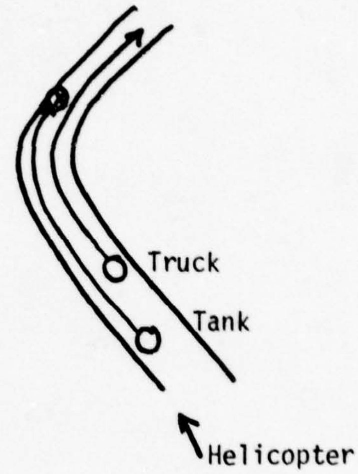


Tape Position 3510

Same geometry as 318 but closer initial range; helicopter flies over when tank has just cleared the APC's.

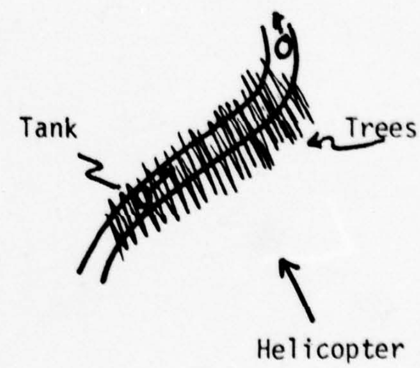
Tape Position 3780

Rear aspect, at close range, of truck and tank moving along road. The truck continues on after going around corner, but tank stops at (x) position and a portion of it is seen as helicopter approaches.



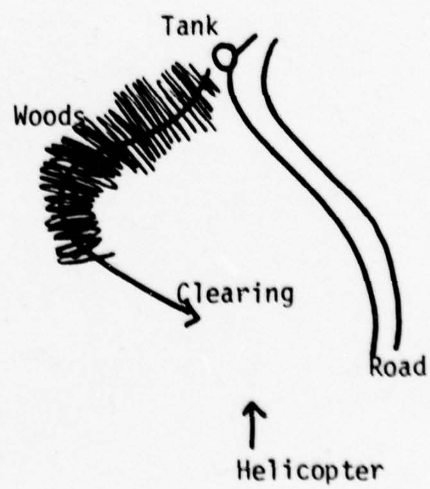
Tape Position 3910

At tape position 3925, one small dot appears. Later, at 4060 dot reappears, larger in size, but with a substantial amount of obscuration. A second target appears and both are partially obscured by a screen of trees as they move along a road. The second target is a tank.



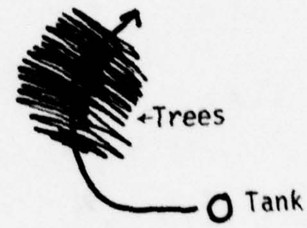
Tape Position 4250

Dark tank is initially positioned on a dark road; the tank then moves off the road into the wooded area. The tank begins moving when the helicopter has closed to approximately medium range.



Tank Position 4580

Close up view of tank as seen through a screen of trees providing partial obscuration; side and rear aspects.

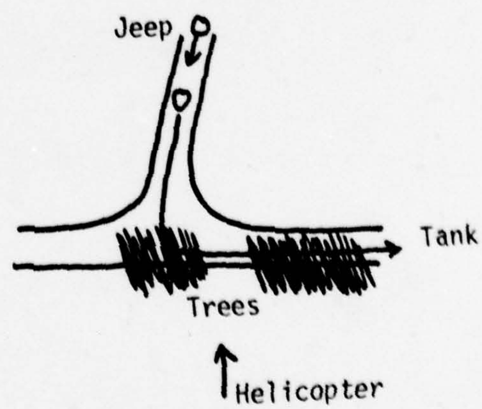


Tank Position 4700

close up view of tank as seen through a screen of trees providing full and then partial obscuration; front view.

Tank Position 4880

Dark tank on a dark road and partially obscured by trees at the road intersection and along the road at the bottom of the Figure. Vehicle following tank is a jeep. Initial range is long.

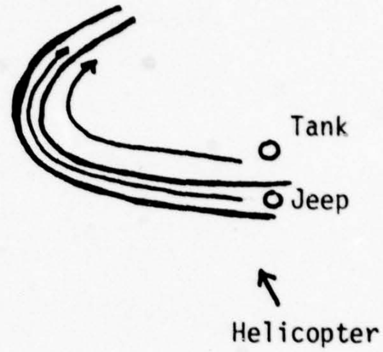


Tank Position 5080

Tank, initially moving on road, moves off onto shoulder. Bottom and treads of tank are obscured. Another vehicle, a jeep, is moving ahead of tank and stays on the road. The tank passes the jeep in the last part of the run.

Tape Position 5280

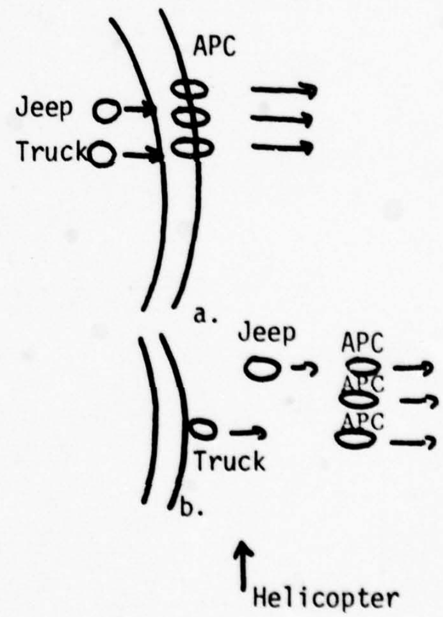
The jeep is moving on the road and the tank on the shoulder. Both targets appear at close range as they go around the curve simultaneously. Run finishes with close range images of the tank seen at rear aspect.



2.2.6 Tape "#2 11/11/77"

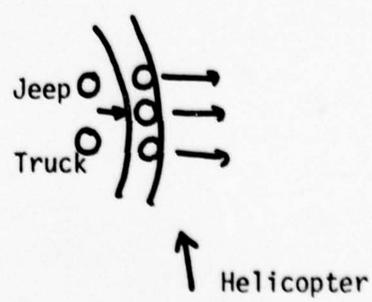
Tape Position 100

The initial target positions are shown in figure a. The jeep and truck shapes are merged and the three APC shapes are merged at long range. The jeep and truck move together across the road where background obscuration occurs with the light targets against the light road. Once across the road, the truck slows and the jeep moves ahead.



Tape Position 390

Same initial position for the jeep and truck but the three APC's are on the road. Further, the jeep and truck stay together this time as do the three APC's when all five targets begin moving from left to right.

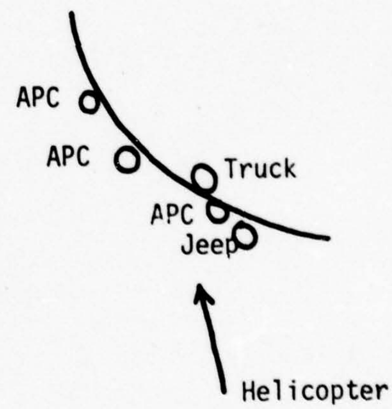


Tape Position 865

Same geometry as 390 except the positions of the jeep and truck are reversed. Most of the run occurs at long range because the initial helicopter range is long and the closing speed is slow. Obscurations are shape merging and background when the light targets are on the road.

Tape Position 1350

There are five targets placed in the trees along the border of a woods. The targets are stationary. Initial range is long and there is shape merging; the right most APC is difficult to distinguish at long range.



Tape Position 1700

Same target geometry as 1350 except approach angle of the helicopter has moved to the left. Obscuration still occurs among the same three targets.

2.3 Classification of NV & EOL Data Base into Difficult Tracking Scenarios

According to Section 2.1, the difficult tracking scenarios were listed and discussed; they are repeated here and labelled with a letter which refers to them from the table of NV & EOL data base tapes.

A. New Background

B1. Target Partially Occluded by an Obstruction

B2. Target Partially Occluded by Terrain Features

C. Target Almost Completely Occluded (Isolated Area Visible)

D. Target Shape Merges with Another Target

Examples of these obscurations are shown in the images of Reference 3.

TABLE 3-1

Difficult Tracking Scenarios in NV & EOL Data Base

TAPE	OBSCURATIONS				
	A	B1	B2	C	D
Tape 11/10/77	1265-1280				1265
Runs 1,2,3	1780-1950				1780
	2032				2032
	2500				2850
	3700				3700
	4300				
	4760				4760
	5000				
Tape 11/11/77	2430				2430
1030 hours	3100				3100
	3700				3700
	4380				4380
	4850				4850
	5330				5330
Tape #4		240	240		240
	500	500	500		500
	830	830	830		830
	1080	1080	1080		1080
	1380	1380	1380		1380
					1870
				2800	

TABLE 3-1

Difficult Tracking Scenarios in NV & EOL Data Base

(Continued)

TAPE	OBSCURATIONS				
	A	B1	B2	C	D
Tape #4 (Continued		3090	3090	3090	3090
		3700	3700	3700	3700
		4400	4400		4400
		4850	4850	4850	
		5300	5300		5300
		5650	5650	5650	5650
		6000		6000	
		6270			6270

TABLE 3-2

Difficult Tracking Scenarios in NV & EOL Data Base

TAPE	OBSCURATIONS				
	A	B1	B2	C	D
Tape #5	2030				2030
	2300				2300
	2560				2560
	2910				2910
	3180				3180
	3510				3510
		3780		3780	
				3910	
		4250	4250	4250	
				4580	
				4700	
	4880	4880		4880	
	5080				
	5280	5280			5280
Tape #2					
	100				100
	390				390
	865				865

3.0 PRELIMINARY RESULTS

The purpose of the section is to describe that portion of the image processing laboratory at Westinghouse where this contract work is being performed, to describe the results of programming the University of Maryland algorithms, and describe the test results of the Westinghouse digital freeze frame device. These items are Westinghouse obligations which were discharged during the first quarter of this contract.

3.1 <u>Westinghouse Image Processing Laboratory</u>

We shall be using the system shown in Figure 3-1 to analyze the data base supplied by NVL.

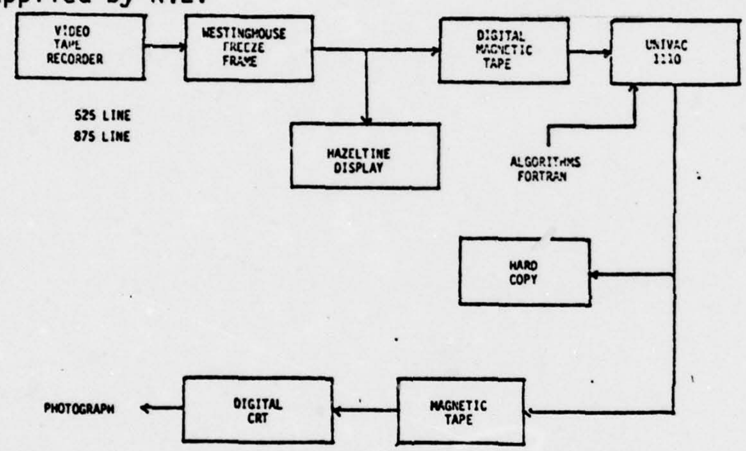


Figure 3-1. Laboratory Set Up

Two video tape recorders are being used, a 525 line ½ inch tape system and an 875 line, GFE, 1 inch tape system. A 125x125 window is snatched by the Westinghouse freeze frame device with a 17 MHz oscillator, digitized and put in a (RAM) Random Access Memory. The RAM is then written (6 bits of data) onto a magnetic tape. The freeze frame device is clocked so that an arbitrary sequence of frames e.g. consecutive or every nth frame can be obtained. The magnetic tape is then read by a Univac 1110 wherein the intelligent tracking algorithms reside. These algorithms are written in Fortran so that change in the algorithms can be accomplished easily in a high order language. After processing the images with the algorithms, a hard copy is available of the resulting images. The processed images can also be put on a magnetic tape and processed by the Westinghouse Simulation Laboratory where Polaroid photographs of the displayed processed images are obtained.

In a typical run, a section of video tape encompassing 750 windows and representing 25 seconds is scanned. From the target velocities seen on the NVL data base, every tenth frame is a decent representation. The representation we are seeking is before the obscuration, during the obscuration, and after the obscuration. From the 75 frames obtained, some of the frames will have no information, because of sensor and platform motion. We will end up with approximately 20 good frames, some depicting each of the above conditions. We feel that we can **synthesize** the intelligent tracking algorithms from such a collection. Having programmed the equations, we can then go back over these sequences and test the equations against every frame to cover the gaps.

3.2 DARPA Algorithms

The DARPA algorithms developed under the SMART sensor contract were described in Appendix A of this report. These algorithms are now programmed in Fortran on the Univac 1110. Figure 3-2 is a scene from the 525 line NVL data base. This frame has been taken from a video tape, digitized, and placed on magnetic tape and then the Univac 1110 disc for processing. After processing, the hard copy was given to NVL at a January meeting and the photographs of digital CRT display are shown in Figures 3-2, 3-3, and 3-4. Figure 3-2 is the scene before processing; Figure 3-3 is the image after median filtering; and Figure 3-4 shows the superposition of the connected components and non maximum suppression algorithms.

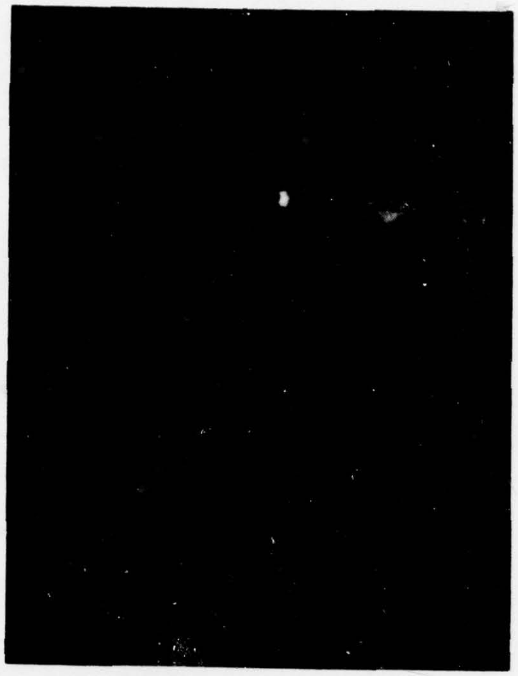


Figure 3-2. Original Digitized Image.

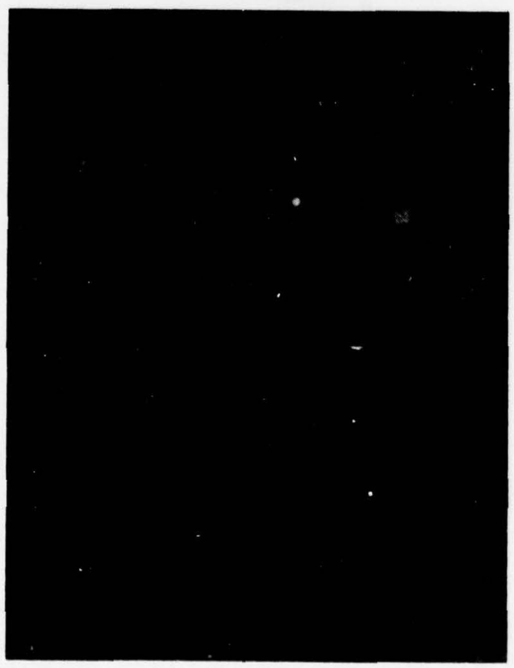


Figure 3-2. Image After Median Filter

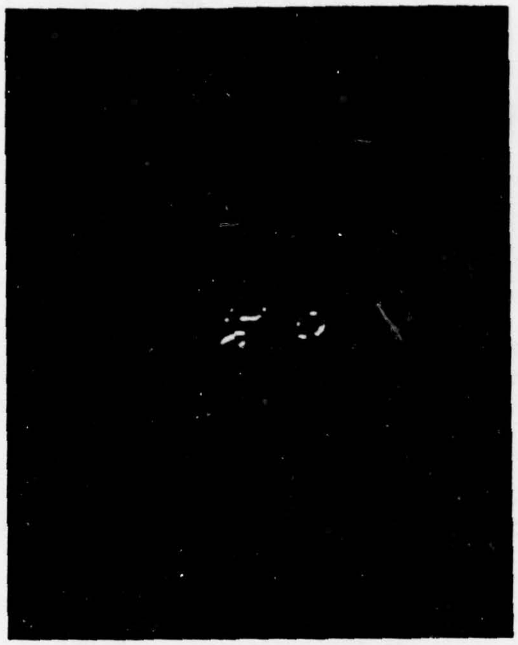


Figure 3-4. Superslice Algorithms Results

Note that the targets were only two or three lines high and the Median Filter was set for 5x5 so that the three targets to the right of the road appear as a single target on the median filtered image. Whereas on the original image, one can just barely discern the separations between the three. In Figure 3-3, the highlights on the target exteriors show the coincidence between perimeter points of the connected components algorithm and the gradients left by the non maximum suppression algorithm.

Figure 3-5 shows the output of the Westinghouse Auto Q system at roughly the same stage of processing. At this point, no attempt is made to take either set of algorithms any further. The thrust is to collect an obscuration data base and then apply the algorithms to it.

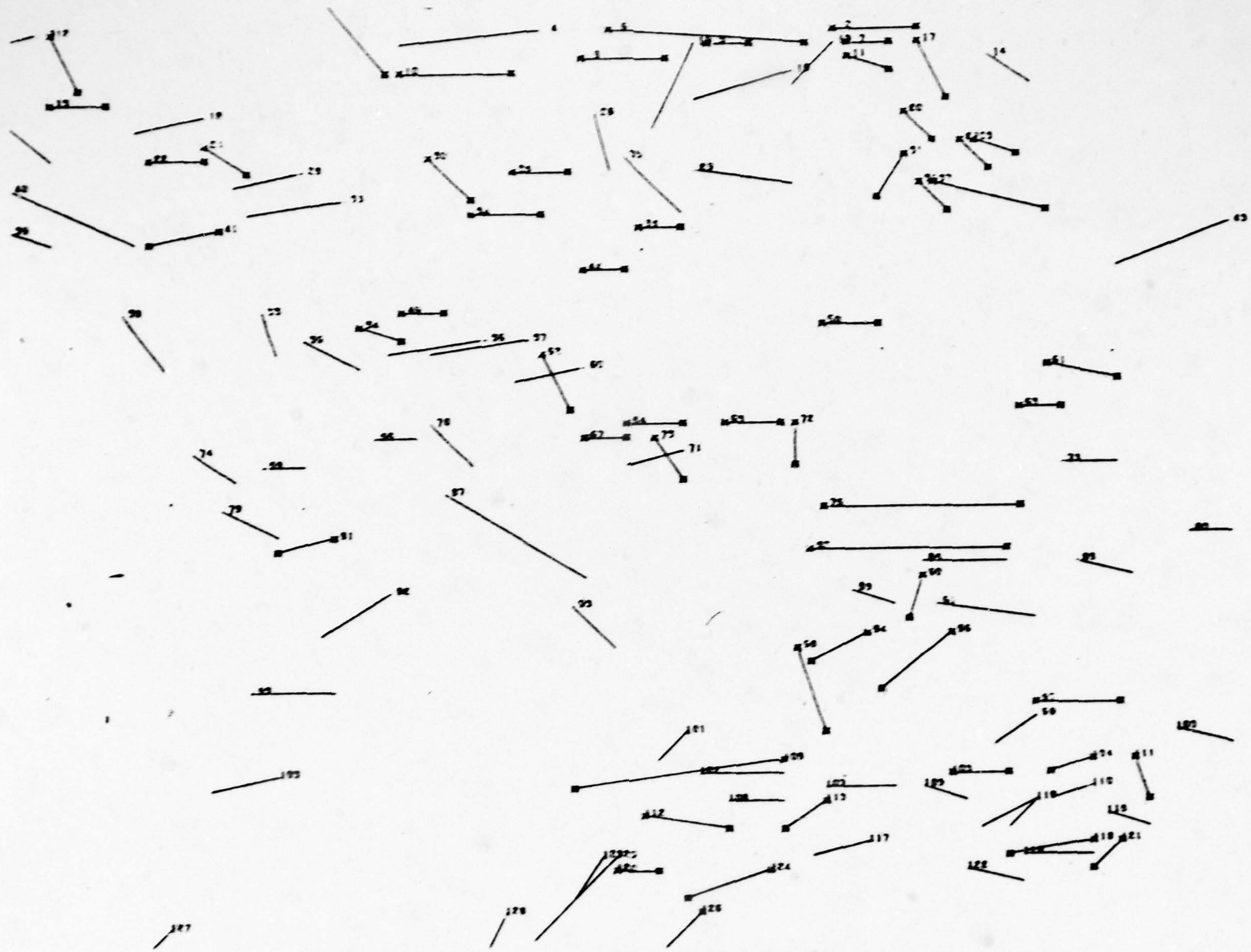


Figure 3-5. Westinghouse AUTO-Q Results

3.3 Westinghouse Freeze Frame Device

As mentioned in Section 3-1, the Device is capable of obtaining an arbitrary sequence of frames. Figures 3-6, 3-7, 3-8, 3-9, and 3-10 show a sequence of frames taken 10 frames apart of a jeep moving on a road. Movement is seen by comparing the crosshairs with the jeep position; it is seen that the jeep is moving from left to right.

The freeze frame device currently snatches a 125x125 pixel window from the image; the position of the window is controlled by a joystick and the window outline is superposed on the videotape image as it appears on the CRT. Layout and construction is underway on a full frame device capable of working on 875 line data.

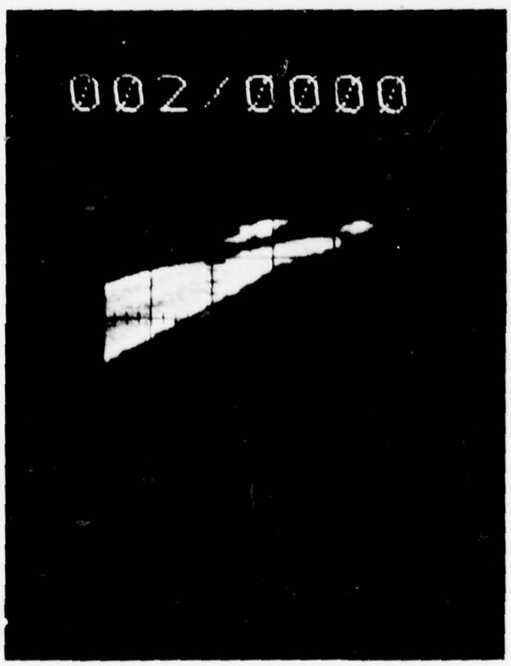


Figure 3-6. Jeep at t_0

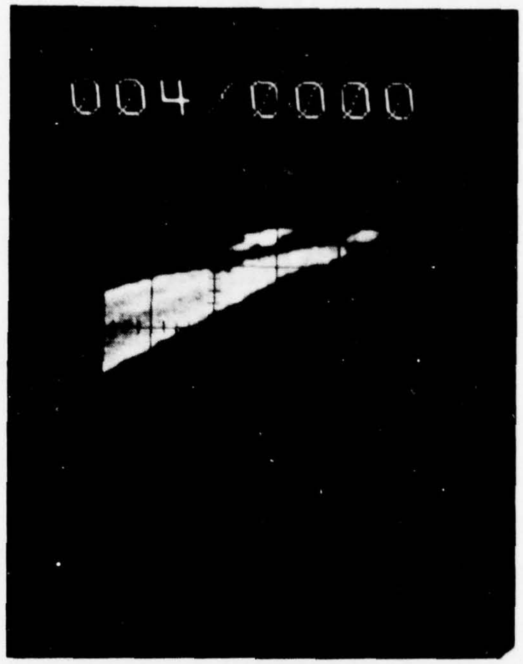


Figure 3-7. Jeep at t_0 + .3 sec.

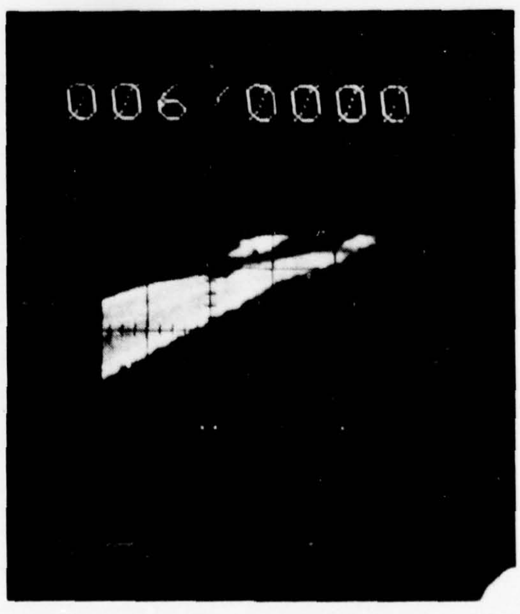


Figure 3-8. Jeep at t_0 + .6 sec.

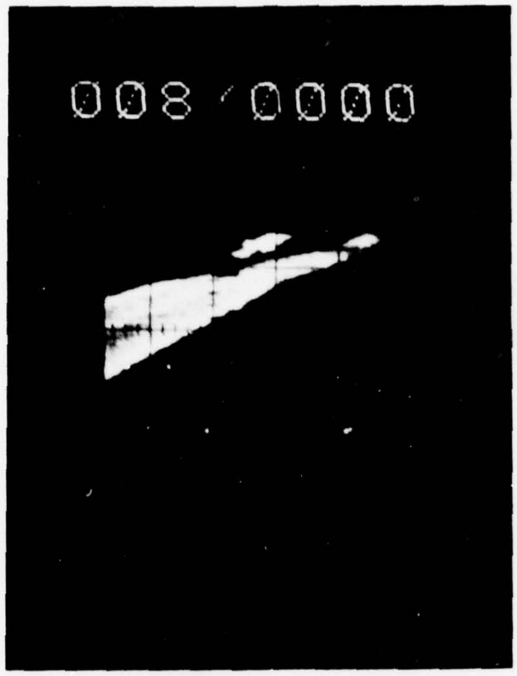


Figure 3-9. Jeep at t_0 + .9 sec.

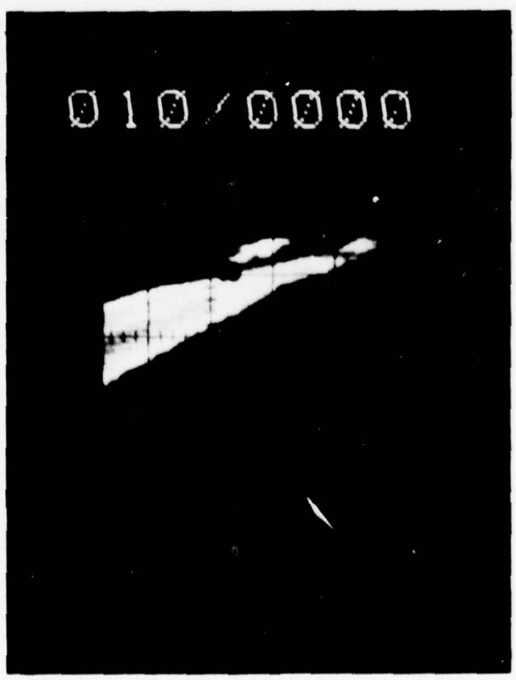
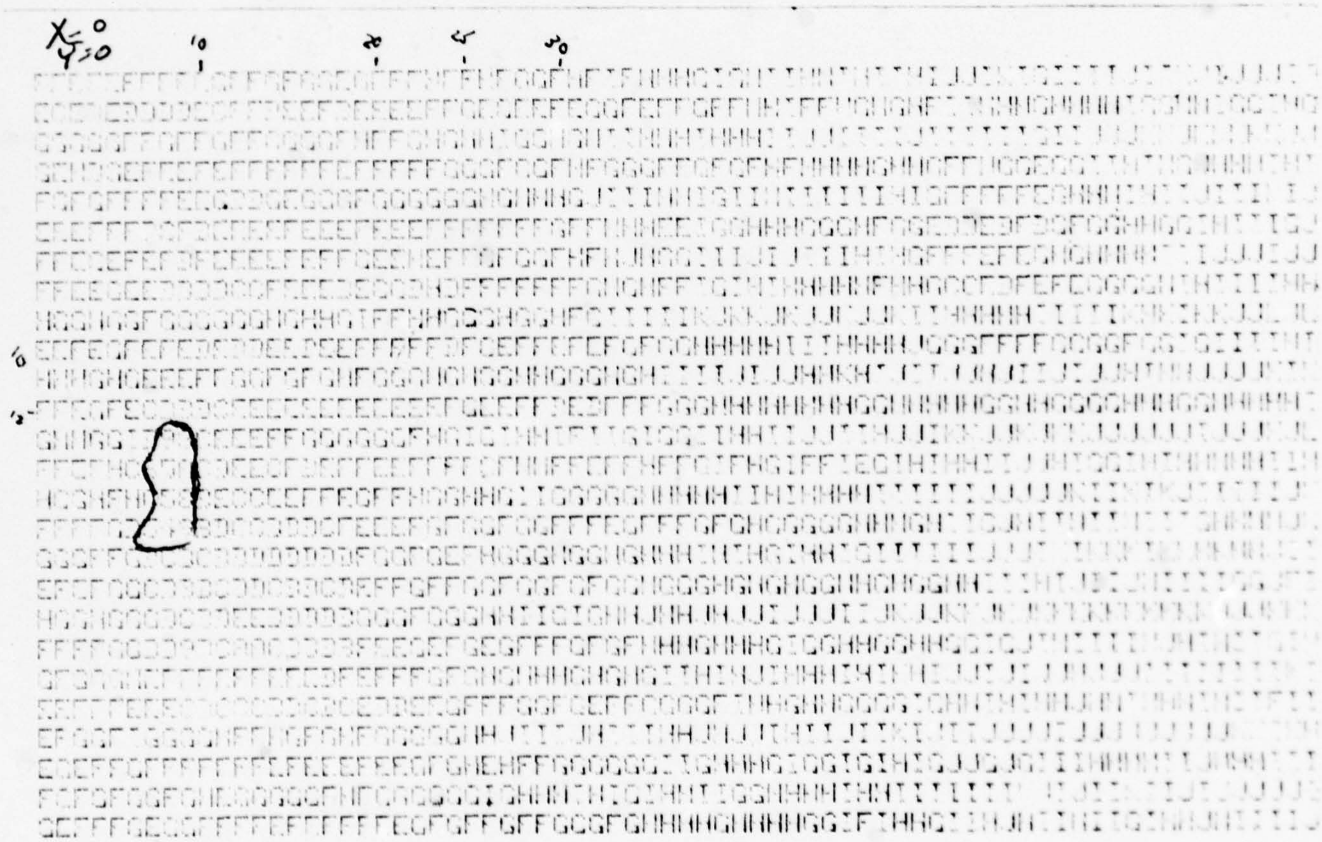


Figure 3-10. Jeep at t_0 + 1.2 sec.

3.4 875 Line Data

Figure 3-11 and 3-12 show results of snatching 875 line video as shown on the Hazeltine Terminal in the lab. The oscillator was 12 MHz for these cases and was then updated to 17 MHz to avoid aliasing. The data came from FLIR Tape "11/7/77, Practice Run, Lothads," at tape position 2500.



WHT, BLK

0 → 9, 10 → 31 GREY SCALE

0 → 9, A → V DISPLAY CHAR.

Figure 3-11. 875 Frame #1

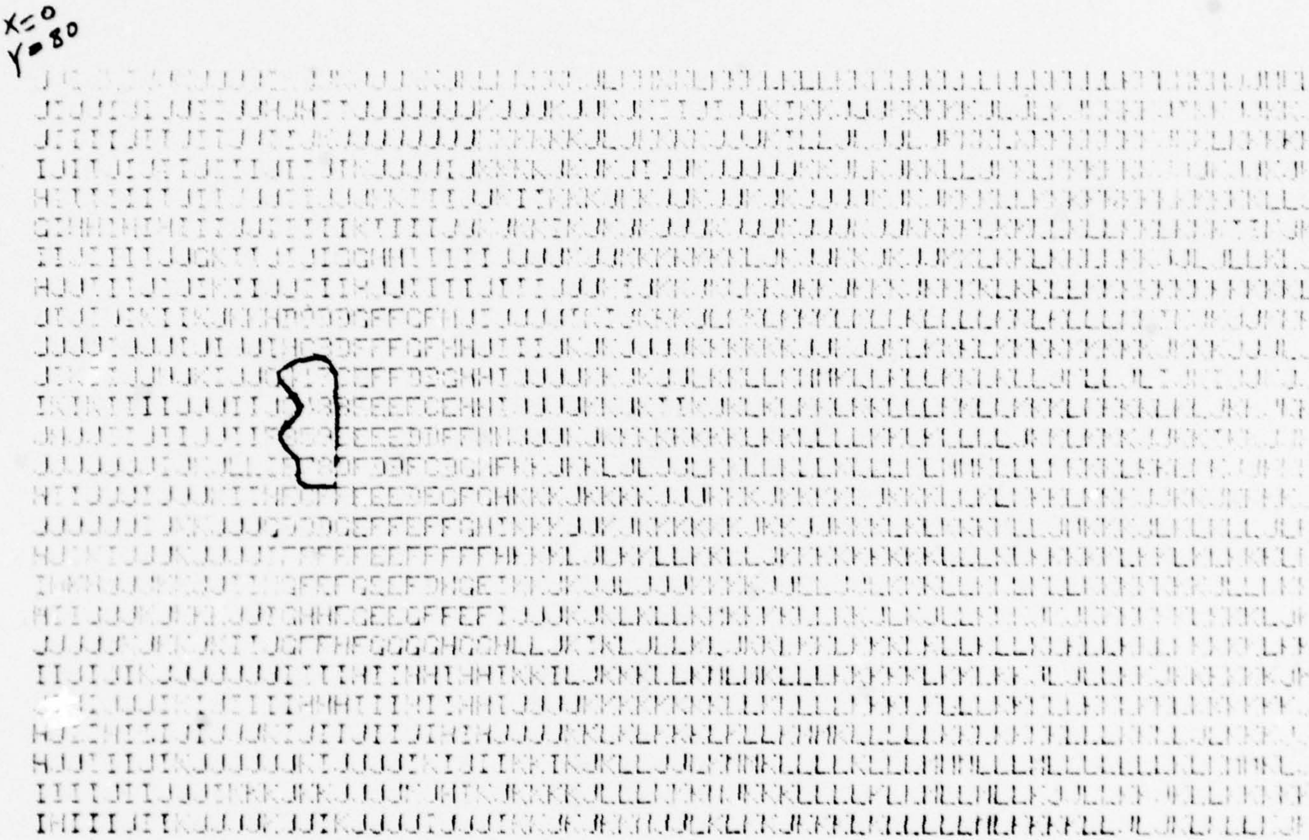


Figure 3-12. 875 Line Frame #2

4.0 REFERENCES

1. Assessment of Target Tracking Techniques, Cpt. B. Reischer, Paper 178-06, SPIE Symposium, April 17-20, 1979, Washington, D.C.

2. Statement of Work, Intelligent Tracking Techniques, Section F.1 (Purpose), Night Vision & Electro-Optical Laboratories, Ft. Belvoir, Va.

3. Intelligent Tracking: A Progress Report, Willett, T.J. & Raimondi, P., Paper 178-07, SPIE Symposium, April 17-20, 1979, Washington, D.C.

4. Algorithms and Hardware Technology for Image Recognition, Final Report of Contract DAAG - 53-76C-013B, March 31, 1978. Univ. of Md - Westinghouse.

APPENDIX A

A.1 APPLICABLE IMAGE PROCESSING TECHNIQUES

A.1.1 Segmentation Techniques

One set of segmentation techniques utilized for this contract was developed by University of Maryland[4] under the auspices of DARPA and NVL. The system flowchart is shown in Figure

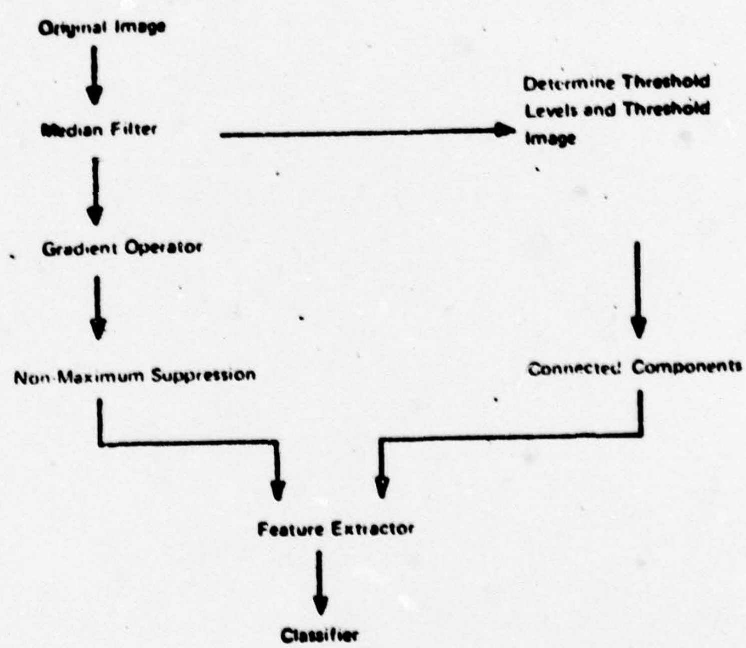


Figure A-1. System Flow Chart

In general, the Median Filter acts to suppress noise. The Gradient Operator extracts edges which are then thinned by the Non-Maximum Suppression Algorithm. At the same time, a set of gray levels is determined and the filtered image is thresholded at each gray level. A Connected Components Algorithm partitions each of the thresholded images into potential object regions. The Super Slice Algorithm correlates perimeter points formed independently by the Non-Maximum Suppression and Connected Components Algorithms and a score is obtained for each gray scale threshold. These scores and several other algorithms form a set of Classification Logic. A short description of each algorithm follows.

The Median Filter acts to extract the median value from a 5x5 pixel window and place that value in the center pixel location; the filter can be considered as a smoothing operator.

The Gradient Operator is an edge detector which is defined as GRAD OP = max $\{|A-B|, |C-D|\}$ where A, B, C, and D each represent the sums of overlapping regions of 4x4 pixels each as seen in Figure A-2. The value of GRAD OP is

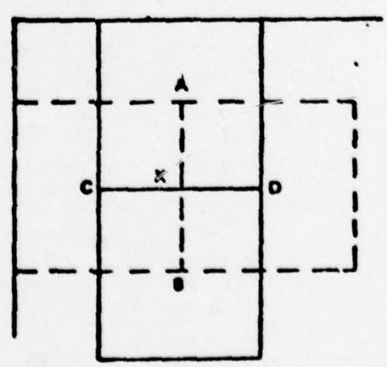


Figure A-2. Gradient Operator

placed in the pixel location marked "X" which is one pixel to the left and above the center of the entire region.

The Gradient Operator extracts edges in either the horizontal or vertical direction; the non-Maximum Suppression Algorithm then looks in a direction perpendicular to the edge for a larger gradient. If a larger value cannot be found, the edge under consideration is retained; the edge is removed if a larger value is found. The Algorithm is shown in Figure A-3. The gradient under consideration is a vertical one and the area examined for larger gradients is in the vertical direction.

The purpose of the Connected Components algorithm is to segment the image data stream into smaller domains. Each small domain includes a single object in the image plane. This algorithm distinguishes between objects and isolates regions so that statistics for Classifiation Logic can be obtained.

```
x x x

x x x

  x           If any x>y, y = 0

  y     →     Otherwise retain y

  x           x, y are gradient values

x x x

x x x
```

Figure A-3. Neighborhood for Non-Maximum Suppression

Assume that the original image has been thresholded and the result is in binary form with gray levels exceeding g_1 shown as 1's in Figure A-4. Two lines are retained in memory so that each pixel can examine its neighbors to the left and right and above and below. No diagonal connections are permitted under this convention and an adjacent (horizontal or vertical) pixel must be occupied in order to make a connection. No skips or gaps

1			1	1	1	1				1	1	
1			1	1	1		1				1	
1			1	1	1		1				1	1
1			1	1	1	1	1				1	
1			1	1	1	1	1	1	1		1	1
									1	1	1	

Figure A-4. Binary Image

are allowed, and the computations start one pixel in from the edge. In Figure A-5 there are four distinct regions, A, B, C, and D. The only possible connection between regions B and C is through a diagonal, which is not allowed in the computations for the fourth row as seen in Figure A-6. Here, there is a connection between regions B and C and an equivalence statement, B = C, is carried along. At the end of the sixth row, there is another connection

A			B	B	B	B				D	D	
A			B	B	B		C				D	
I			I	I	I		I				I	I
I			I	I	I	I	I				I	
I			I	I	I	I	I	I	I		I	I
									I	I	I	

Figure A-5. Computations for the Second Row

A			B	B	B	B				D	D	
A			B	B	B		C				D	
A			B	B	B		C				D	D
A			B	B	B	C	C				D	
I			I	I	I	I	I	I	I		I	I
									I	I	I	

Figure A-6. Computations for the Fourth Row between C and D (C=D) and all the regions are completed as seen in Figure A-8.

A			B	B	B	B				B	B	
A			B	B	B		B				B	B
A			B	B	B		B				B	
A			B	B	B		B				B	
A			B	B	B	B	B	B	B		B	B
									B	B	B	

Figure A-7. Completed Image

The areas of A, B, C, and D are computed by cumulating the number of pixels assigned to each. The perimeter is calculated by cummulating the number of pixels assigned to each region which are neighbors of zeroes. Each pixel has eight neighbors; a perimeter point is defined as having at least one zero neighbor, similarly an interior point is defined as having eight non-zero neighbors.

The Super Slice Algorithm selects the appropriate threshold by matching the set of Non-Maximum Suppression outputs with the perimeter points of Connected Components for each threshold. Thus, each object may have a different threshold value than some other object within the same image.

Another approach to segmentation to be explored under this contract is that of the Westinghouse Auto-Q system which is briefly described in the next paragraphs. Three types of data are extracted. The primary data are the straight-line contours of gray-level gradient. Thus, a line-drawing of the video image is generated. The second type of data are positional cues of gray-level closed objects (or "blobs"). The location of a blob generates a window within which recognition features are generated. The final set of data are statistical parameters computed during the preprocessing which may be used in texture classification.

Operation of the preprocessor is on a line-by-line basis with respect to the input image. Therefore, video data may be handled directly. Furthermore, storage requirements in the preprocessor are limited to single lines of data only.

To generate the straight-line contours (subsets) of the image, it is necessary to first compute the two-dimensional gradient at each image point. This is done as shown in figure A-8 with a four-pixel window scanning across the image in a raster format. The gradient amplitude and angle are approximated as shown. The gradient direction is quantized to 16 discrete directions, as depicted in the diagram. To suppress the areas of negligible gradient activity (containing no significant contour or edge information), a threshold is applied to the gradient amplitude.

After gradient thresholding the edges are generally still too wide for subset generation. Therefore, a gradient thinning operation is performed. The operation basically "skeletonizes" adjacent colinear gradient directions to the peak or maximum points.

The algorithm utilizes a raster scanning window containing a gradient cell "X" and 4 of its nearest neighbors. The scanning window is depicted at the top of figure A-9. The neighbors with colinear gradients are compared to "X". The largest gradient is then retained. This procedure is repeated sequentially for each gradient point in the image.

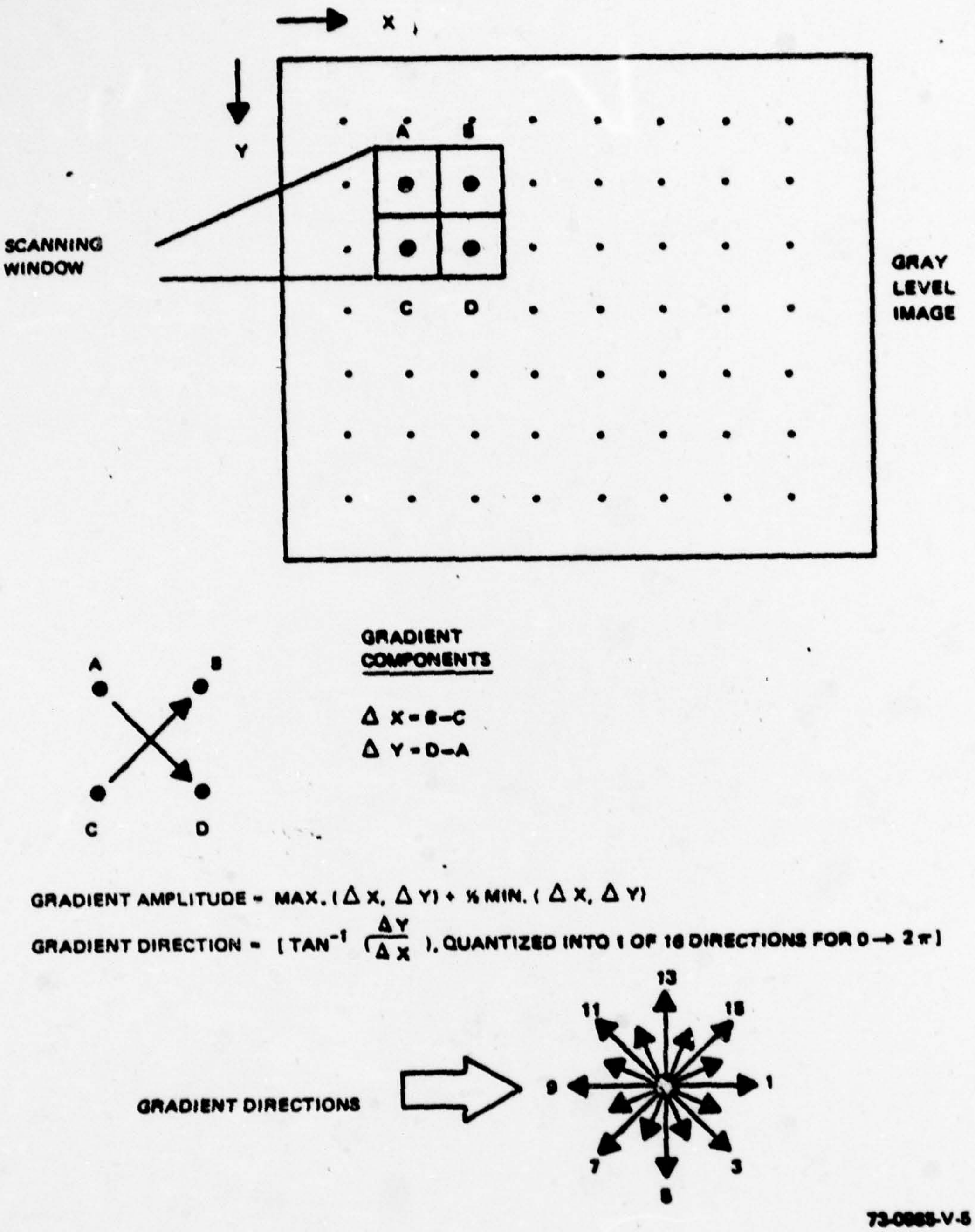


Figure A-8. Gradient Extraction Process

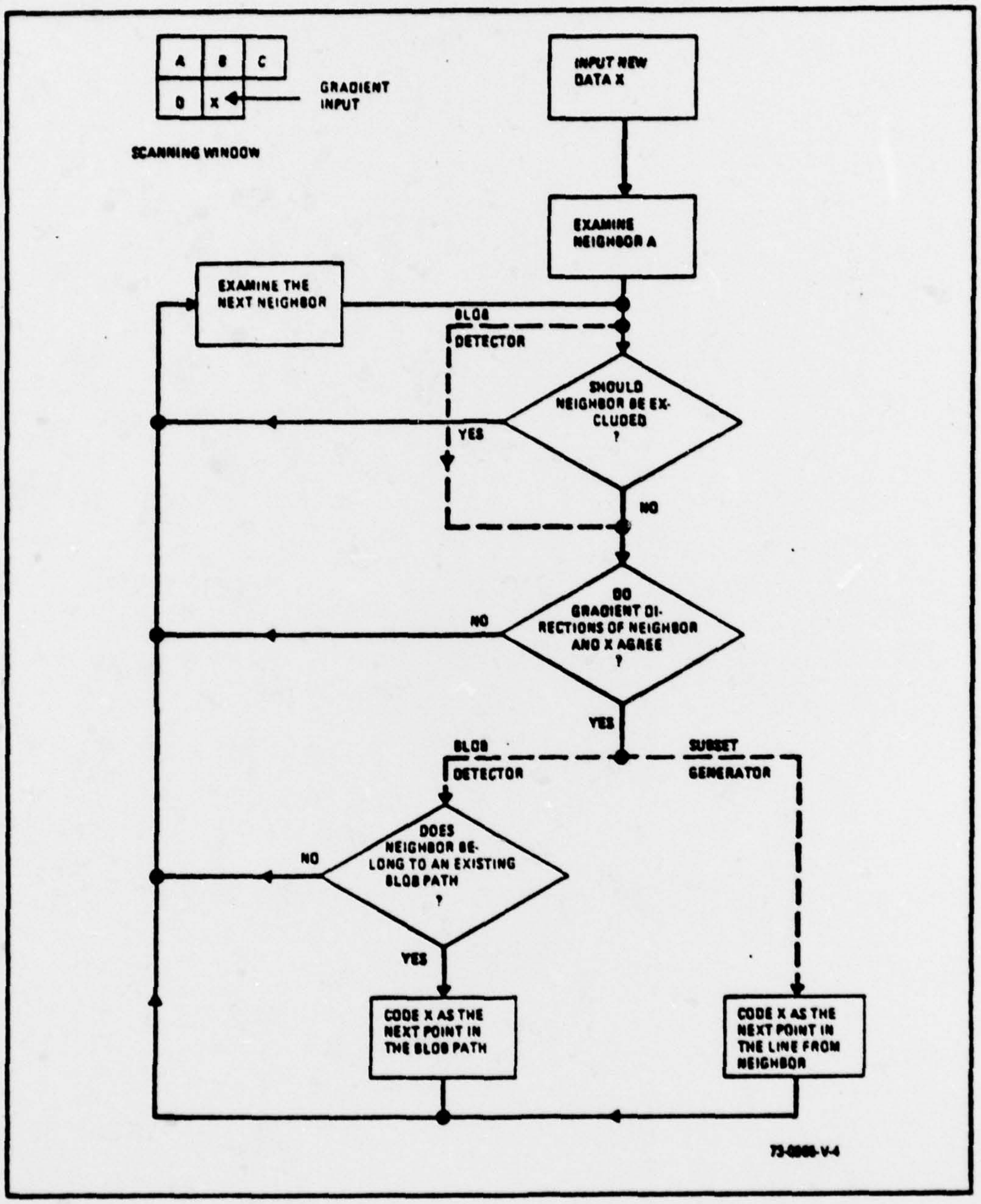


Figure A-9. Block Biagram - Blob Detector and Subset Generator - Operational Cycle

Subset generation is accomplished by "growing" a line formed by adjacent parallel gradients. As before, a 5-cell scanning window is employed. The new data point is labeled cell "X". Its four neighbors are examined (sequentially: A, B, C, then D) to find those containing a parallel (within a tolerance) gradient direction. If one is found, then "X" is added as the next point in the line from the neighbor. Neighbors that are colinear to the gradient of "X" are excluded to prevent false lines from forming. The operational cycle of the subset generator is diagrammed in figure 1-11.

The blob detector detects the presence of a contiguous area of gray levels lighter (or darker) than its surrounding background. It operates independently of size, orientation, and position, and will detect all but sharp, concave shapes.

The operation of the blob detector is similar to that of the subset generator. The input data is the output of the gradient stage. Basically, the blob detector seeks to trace paths along contiguous, slowly changing gradient directions. Bookkeeping counters for each path being traced keep track of the gradient at the start of the path. When two paths from the same starting gradient join, a blob detection occurs. Additional bookkeeping counters measure the maximum and minimum X and Y excursions, providing a measure of the blob's size.

Figure A-9 depicts the operational cycle of the blob detector. It uses the basic 5-cell window scanning the gradient image. Each of the four (4) neighbors of the X-pixel is examined to determine if X should be added as the next point in a blob tracing path. The output of the blob detector consists of the blob polarity, center position, and horizontal and vertical dimensions. This data permits the object to be isolated for feature extraction.

The third preprocessor function is the collection of statistical data for texture classification. The gray level image area is divided into windows of 30 x 30 pixels for statistical data collection. The average gray level and average gradient amplitude is computed. A limited histogram of the gradients is accumulated; i.e., the number of pixels with gradient amplitude equal to zero, one, two, and three. Also, two additional parameters are computed: (1) the number of pixels with gray level > a, and (2), the number of pixels with gray level < b. The subset generator provides two statistics: (1) the number of subsets per window, and (2) the number of "long" subsets.

The final processing of the data is accomplished in a programmable processor (general-purpose computer). Its task is to generate the recognition features and perform the target decision logic. A block diagram of the final processor is shown in figure A-10.

1.3.2 Blobs and Groups

To reduce storage and speed requirements and to reduce background interference, recognition features are not computed for the entire image. Instead, they are initially computed only within local rectangular areas whose positions are designated by the blob detector. Therefore, the blob detector in effect "cues" the processor to a local area containing a possible target. However, for those targets having complex shapes, such as aircraft, cues are also initiated by the presence of a "starter" subset. A starter subset is defined as one whose length exceeds a predetermined value (e.g., $l > 5$). For each starter subset within the image, a square area (or window) centered on the subset is also used as a positional cue for the processor. The blob and long subset windows are used to collect groups of subsets, as will be discussed later.

As seen from figure A-10 the first function performed by the processor is blob merging. Under certain conditions a single target can give rise to

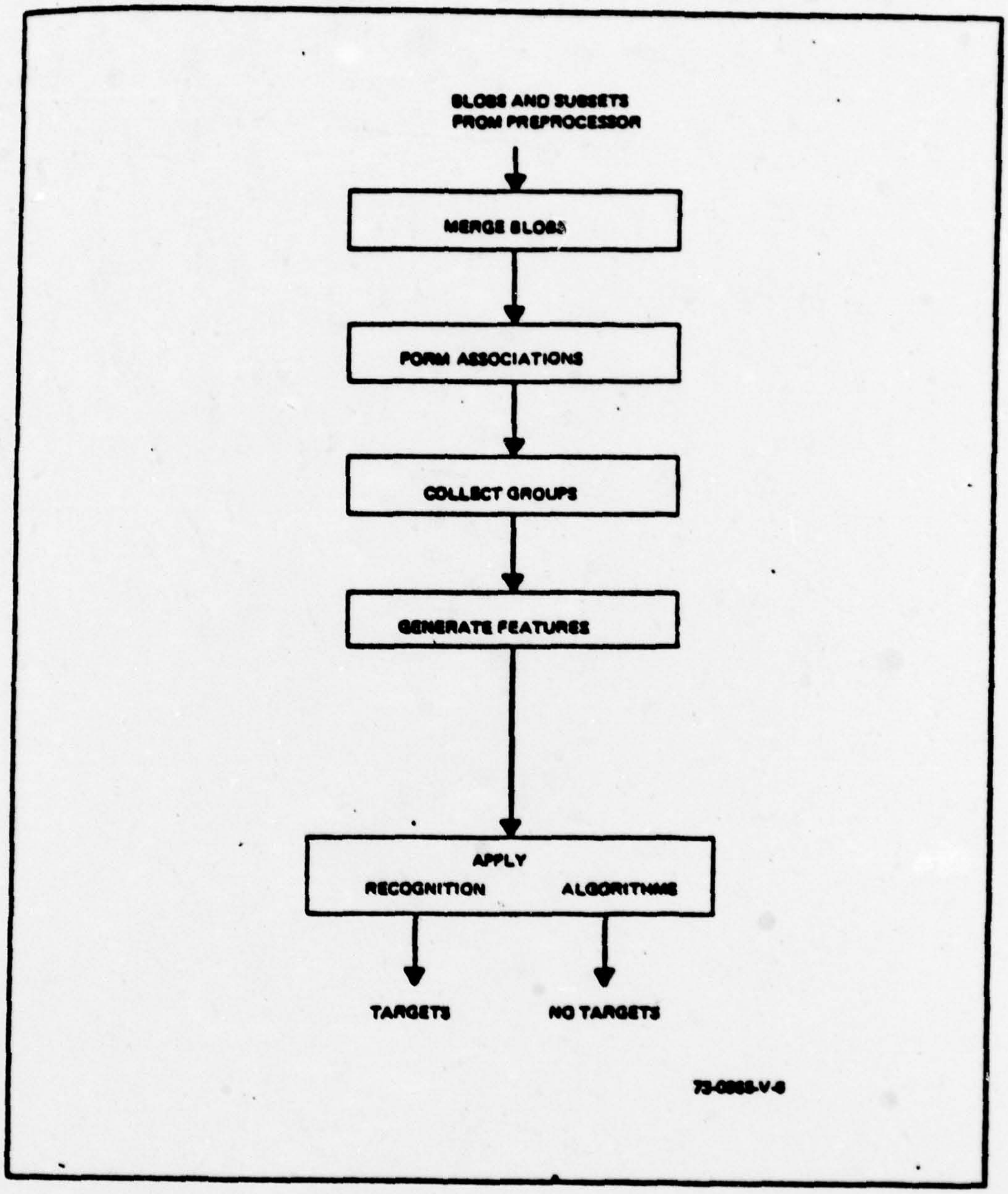


Figure A-10. Final Processor

multiple (usually no more than two) blob detections that overlap. Therefore, the blob list in the preprocessor buffer stage is scanned for blobs with overlapping areas. Overlapping blobs are merged into a single new blob whose area will enclose the union of the original blbo areas. See figure A-11.

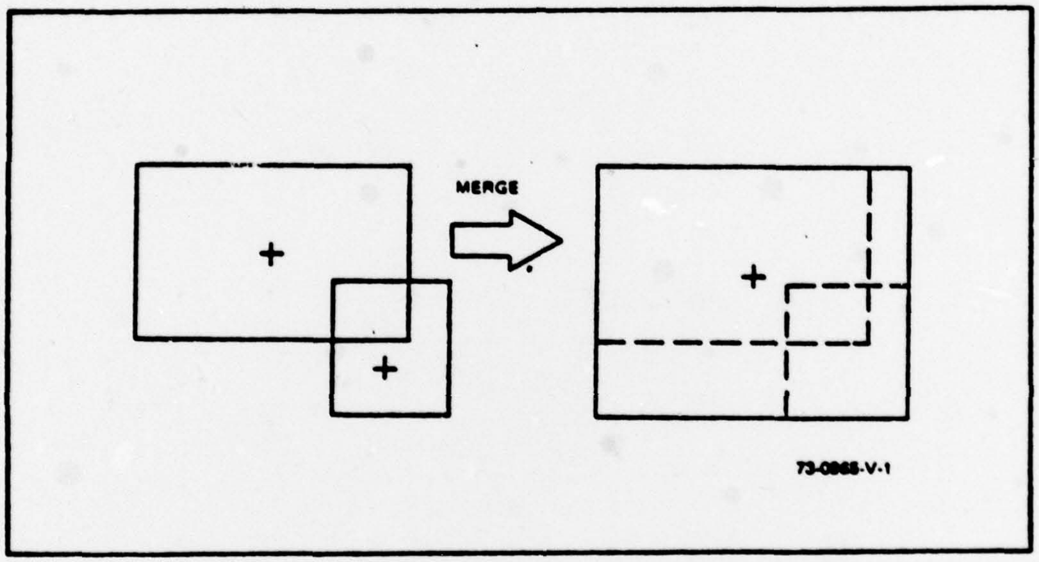


Figure A-11. Blob Merging

Following blob merging a search is made for several different "associations". In general, an "association" means that an element (e.g., blob) is within a specified distance from another element. An association of long subsets with other long subsets is a significant association. These pairings may later be screened to detect the presence of roads. Also the association of blobs with long subsets is examined. Subsequently, these long subsets are prevented from being used to collect a subset group, since the blob is usually a more accurate cue.

When the associations have been made the process of group forming starts. Each blob or long subset defines a window. For each window, all subsets are screened by X-Y position. All the subsets falling within the window are defined as the group for that window.

Further screening of the groups is done to eliminate subsets not belonging to a condidate target area. It should be noted that the gradients of the subsets belonging to any dark (light) object point inwards (outwards), with few exceptions. See figure A-12.

Subset pairs with non-opposing (inconsistent) polarities do not usually belong to an object, but are merely background clutter. Therefore, long subset groups are screened of any subsets with polarities inconsistent with the long subset defining the group. Blob groups are screened of any subsets with polarities inconsistent with the blob color, and relative to its center.

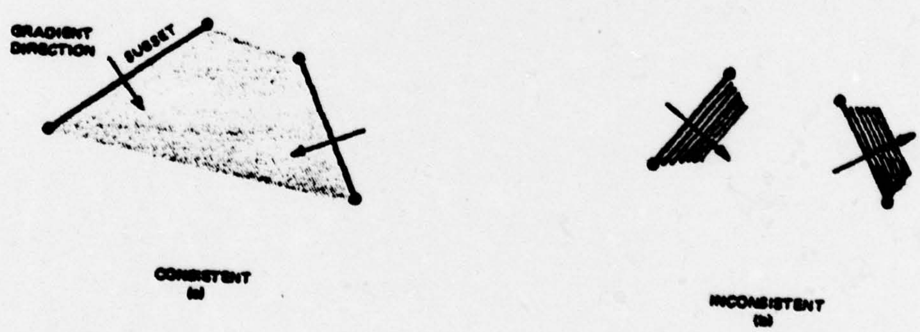


Figure A-12. Significance of Polarities Between Subsets